DOCUMENT RESUME

ED 129 337 IR 004 124

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TITLE	Design of Training Aids and Devices.
INSTITUTION	American Institutes for Research in the Behavioral Sciences, Washington, D.C.
SPONS AGENCY	Office of Naval Research, Washington, D.C.
REPORT NO	AIR-290-60-FR-225
PUB DATE	60
CONTRACT	NONR-2700(00)
NOTE	75p.; Chapter two from "Human Factors Methods for System Design" edited by John D. Folley, Jr.; Archival document
EDRS PRICE	MF-$0.83 HC-$3.50 Plus Postage.
DESCRIPTORS	*Instructional Aids; Instructional Design; *Simulators; Training

ABSTRACT

Training devices should be designed to provide efficient learning conditions, especially guided practice and prompt feedback. These devices can be more useful than their operational equipment counterparts because they facilitate the focusing of learner attention on particular components of a total operation, they make operations visible for study, and they provide opportunity for ample student practice within allowable budgets. Design of these devices should begin from an analysis of performance objectives, the skills needed to meet them, and the characteristics of the trainees. Various training devices are particularly suited to the teaching of identification, facts and relationships, principles, sequential or variable procedures, diagnostic or motor skills. Classroom instructors may employ visual aids to assist them in their training functions. Use of mock-ups, animated wall displays, transparencies, wall charts and films should be aimed at motivating students and maximizing their personal response to the instruction. Photographs and drawings of training devices used in aviation and electronics illustrate the report. (KB)

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DESIGN OF TRAINING AIDS AND DEVICES

Arthur A. Lumsdaine

Dr. Charles W. Bray and Dr. Robert M. Gagné provided many helpful suggestions in their reviews of a draft of this chapter. Their assistance is gratefully acknowledged.

Some Basic Considerations in Training-Device Design

What Is "Training?"

When we say a man is "in training"--say, for an athletic contest or for military service in the infantry--we are likely to have in mind either of two different things. One is the process of physical hardening or toughening that builds strength and endurance. The other is the acquisition and perfection of physical and mental skills acquired through practice, coaching and study. Sometimes the two are built through the same events--for example, practice in pitching a baseball may serve both to strengthen and to perfect the skilled motor coordination needed to get the ball over the plate.

However, it is important to distinguish the two meanings of "training." Otherwise it is easy to make faulty assumptions about what is required of a training procedure or a piece of training equipment. In this book we are primarily concerned with training in the latter sense--developing required human capabilities through the learning of skills and knowledges that are needed for performing technical duties in military or industrial jobs. We will assume that the capabilities required have been identified through procedures such as those described in Chapters 2, 3 and 9.

To develop these capabilities, we need to arrange efficient conditions of learning. For these, mere exercise or practice is not necessarily enough. Conditions of practice are needed that will lead the trainee to practice doing the right thing at the right time, to enable him to correct his errors, to learn necessary discriminations. Almost any form of physical exercise may help serve the ends of "training" in the toughening sense. But only well-designed learning situations will train effectively in the sense of teaching. Without these, the practice or exercise may serve no purpose. It may waste instructional time on irrelevant activities. Worse, it may result in mistraining--teaching a man habits or information that will hinder job performance rather than help it.

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Classes of Training Devices

By a "training device" we mean any arrangement of equipment, components, apparatus or materials that provides conditions to help a trainee to learn a task more efficiently than he could otherwise do. By a "task" we mean something he needs to be able to do in order to fill a specified job in a military or industrial organization or similar institution--e.g., the many diverse tasks required in piloting a B-58 bomber, troubleshooting a fire-control system, overhauling a truck motor, operating a station in a communication network, or programming a digital computer.

Training devices include various forms of two-dimensional displays of verbal, symbolic or pictorial nature, including motion pictures and other forms of projected materials such as slides and transparencies, as well as wall charts and the like. They also include various configurations of real or simulated three-dimensional components arranged either as a student-operated trainer or as a classroom display.

Within the general field of training devices, we sometimes make a distinction between training aids and training equipment. Actually this discrimination is a quite fuzzy one, partly because there is more than one basis for distinction, so that different persons and different organizations don't always agree on the usage of the terms. For this reason, we will not attempt to make a rigid, air-tight classification.

In general, though, we can say that training aids are usually devices that are used by an instructor, often in a classroom, to help him present a subject matter. They may be either two-dimensional aids (such as charts or slides), or may include equipment mock-ups or components. The term training aids is also sometimes used to refer to devices used to present training materials--for example, projectors or tape recorders.

The term training equipment is sometimes used also to refer to projectors or similar devices, but more often it implies a specialized kind of equipment which provides for some form of active practice by a trainee. However, since such distinctions are not hard and fast, we will most often use the general term "devices" except when the more restrictive terms "aids" or "equipment" seem clearly more appropriate.

A simulator is a more or less separate class of training equipment which, as the name implies, attempts to reproduce or simulate an operational situation. Extent of simulation is of course a matter of degree, and any device which provides for direct practice of important job tasks is in a sense a simulator. However, the term is most often applied to highly complex training devices such as flight simulators that attempt to reproduce fully all of the operational characteristics of an aircraft, including the way it responds to the pilot's control actions.

In general, such flight simulators and other very complex total-system simulators will not be treated explicitly in the present chapter. This exclusion applies to simulators for complex team operations, and also to simulators which provide total simulation of the environmental situation faced by the pilot of advanced flight systems such as a B-58 bomber. However, the scope of the chapter does include training equipment in the form of "part-task" trainers for effective teaching of component skills and procedures on which more complex operations must be built.

Some of the basic principles dealt with here in the case of simpler devices are, of course, also applicable to the design of complex-system simulators. Their successful application in a complex simulator, however, generally demands the skills of a human factors engineering staff with advanced experience. The present chapter is intended, on the other hand, primarily for the less experienced training-equipment designer who is concerned with training men to perform tasks required in (1) operating and maintaining somewhat less complex systems or (2) performing specific technical duties on components or particular aspects of complex-system operation and maintenance.

Why Do We Need Training Devices?

This simple-sounding question is really not such a simple one because it really includes several related questions. The answers to these questions help point up some of the needed characteristics for good training devices.

Use of Operational Equipment: If we are training an equipment operator, why not train him with the real equipment? There are several answers to this. One is: Sometimes we should, and do. This is particularly likely if the equipment and the tasks it requires are fairly simple ones--say, cleaning a rifle or perhaps adjusting a carburetor. It is unlikely that we would want to construct a special substitute for the rifle which would be better than working with the real thing for training. Even here, though, some charts or even a demonstration film may be very useful as training aids to guide the student through the proper steps of assembly or disassembly of the weapon. And we may want to use an old or inexpensive rifle until skills and precautions are learned so the trainee will not ignorantly damage a fine piece.

But more often the problem is not so simple. The real equipment may be scarce, or even nonexistent. This is the case, for example when one is conducting training in advance for maintenance of a weapons system that is still under development. Even if available, the real equipment may be very expensive, and for many aspects of training a simpler, cheaper substitute may serve as well. Furthermore, practicing on the real equipment before necessary basic skills and knowledges are mastered may be hazardous to personnel as well as damaging to the equipment.

The Need for "Feedback" in Training: Less obviously, even when none of the above reasons apply, the real equipment may not provide efficient conditions for training. One crucial need for efficient learning is a way to guide the student to perform correctly so he does not make errors--or, if he makes them, to inform him immediately and show how to correct them. With many kinds of complex equipment or systems, this kind of immediate feedback to the student or operator is lacking: The consequences of an error may not be apparent until much too late. The apparatus features that are needed to prevent, report and correct errors efficiently to the novice may be undesirable or unfeasible in the operational equipment--for reasons of space, weight, complexity, or cost.

Providing these features in the training situation may involve a training device in which accessory apparatus is added to the operational equipment. Alternatively, it may be better to construct a special device especially for purposes of training. This can have the features needed for effective learning, but does not necessarily require all the components or features of the operational equipment. Thus, the training device may be more costly than the latter, or may be much less costly.

Concentrating on the Crucial Job Operations: Another important characteristic of an efficient learning situation is that the trainee is given ample opportunity to practice all the various operations he may have to perform on the job. Often this is not feasible in the operational situation.

Consider the case of troubleshooting, or diagnosis of malfunctions. For complex equipment systems this is one of the most important and often most difficult tasks that faces us in training a maintenance technician. But a well-designed piece of operational equipment may malfunction only rarely. Certain types of malfunctions may occur very infrequently indeed. Consequently, in order to provide adequate practice in identifying or diagnosing these malfunctions in operational equipment, the malfunctions would have to be inserted artificially.

This may be unfeasible for a variety of reasons. It may be too expensive, too dangerous, too costly, or too time consuming. Therefore, to get efficient conditions for training, we need to provide a training device that permits all normally encountered malfunction symptoms to be inserted readily and observed in a way that provides for efficient practice in diagnosing and correcting them. Further, we want a device that requires the trainee to perform the proper checking sequences to identify the malfunctioning element in the system. However, we want to do this as efficiently as possible and not waste the trainee's time on parts of the operation that are not essential to what he has to learn.

For example, many checking and adjustment procedures require access to internal parts that are difficult and time consuming to get at. It may be necessary to disassemble a complex assembly, or remove a cover plate with 20 screws, in order to get at the part to be worked with. On the job this may be partly inevitable (however, see Chapter 6 on design of equipment for ease of maintenance). But in a training situation an important principle is that most of the student's time should be devoted to learning the things that are difficult to learn. Readily learned (or already learned) routine aspects of a task should therefore be dispensed with. The student should not waste a large amount of instruction time unscrewing bolts or making other unnecessary preparations for getting at the elements of equipment on which practice is most needed.

Sometimes this condition can be met by adapting operational equipment--starting with it already partly disassembled, holding on a cover plate with just two screws, and so forth. Often, however, efficient utilization of a student's time requires special equipment designed expressly so that most of this time can be devoted to the kinds of practice that he needs most to get.

Somewhat similar considerations apply in training the operator of complex equipment systems. Certain emergency procedures are required for situations which must be met when and if they do arise, but which arise seldom and which it would be very dangerous or impossibly expensive to produce deliberately to serve the purposes of training. Some more feasible way must be had to simulate the essential elements of such situations so that the trainee can learn to deal with them effectively. Often the only practical way to do this is to design a training device that will accomplish this simulation.

Making Operations Visible for Study: Among the classes of things needing to be learned as prerequisites to training in actual operations, there are often certain terms, concepts or principles that apply to the operation of a system. Often actual equipment does not reveal these clearly. For example, relationships between internal moving parts of a mechanism, or feedback in an electronic system, cannot be directly observed in the operating equipment. If they are to be seen at all, a special device is then necessary so that they can be observed and studied by the student.

Cheaper Devices May Be as Good--or Better: Learning to identify components and their interconnections generally does not require operational equipment; photographs or drawings often will obviously show substantially the same visual display, and are vastly cheaper.

The factor of cost has both direct and indirect effects. Not only may use of adequate surrogates reduce total cost of training; the fact that many copies of a low-cost substitute (picture or inexpensive mock-up) can be procured means that each student can have one, on which he can study or practice on identifications and procedural sequences for as much time as needed for him to master what he should learn.

With expensive equipment, time per student is limited; the student then does not get enough work to master the task. The importance of this consideration is hard to overestimate. It applies not only in deciding whether to use operational equipment or a training device, but also in deciding whether to buy a few expensive training devices with a limited time quota for each student, or to buy cheaper devices on a one-per-student basis.

The foregoing discussion of why we may need training devices has served also to introduce several important notions and principles that affect their effective design, selection and use. These and other principles developed below can provide important guides for making better decisions about the characteristics a training device should have to do its job most effectively.

Basic Knowledge Needed in Designing Training Devices

Since training devices should exist only to aid learning, knowledge of psychological factors affecting efficient learning is essential. This principle may seem obvious enough, though in current practice it is often not complied with. What is perhaps not so obvious is that, as a consequence, the designer of a training device needs to know something about the factors that make for efficient learning before he can even start to make an intelligent analysis of the functional requirements for a training device. He need not be an expert in the psychology of human learning, but he must understand a few fundamental notions concerning the stimulus and response conditions that govern the efficient acquisition, retention and transfer of knowledges and skills (See also Chapter 10). To present even the rudiments of these notions would require more space than is available in the present chapter. The reader who has not had at least the equivalent of a fairly recent course covering the psychology of human learning and its practical applications to training should therefore consult a good reference to provide this background. In many ways the best concise reference that is published at present is the chapter by Gagné and Bolles (1959). Some other helpful references are the reports by Glaser and Glanzer (1958) and by Miller (1953b), and the recent text by Gagné and Fleishman (1959).

Summary

The main principles and concepts thus far discussed can be summarized in terms of the following guidelines, which for brevity are stated in somewhat oversimplified terms:

1. Training devices should be designed to provide efficient conditions of learning--such as guided practice, prompt correction of errors, basis for necessary discriminations.

2. These conditions can often be met by relatively inexpensive training aids and devices designed to teach specific tasks, and are also important in more complex simulators (which are not covered in this chapter).

3. Operational equipment can be used for training when it is readily available, when it provides safely for efficient conditions of learning, and when cheaper substitutes would not do as well.

4. Training devices rather than operational equipment are often needed to provide proper feedback to the student, to permit ample student practice on crucial job operations, to make operations visible for study, or to provide opportunity for sufficient student practice within allowable budgets.

5. Training devices should be designed so that most of the student's time is spent practicing the things that are difficult to learn. Their design should be based on application of psychological principles governing effective learning.

Identifying the Requirements for Training

The First Questions to Answer

When we start to design any procedure or device that is to be used to train people we must first deal with three questions. Guidance in answering these questions is contained in the earlier chapters indicated. The questions are:

1. What is the final human performance that we want to attain? (See Chapters 2 and 9.)

2. What are the specific things that need to be learned to make this criterion performance possible? (See Chapter 3, concerning kinds of skills and knowledges, and Chapter 7, concerning influence of job aids on what needs to be learned.)

3. Who is to learn them--what are his abilities and motivations, what parts of the total required skills and knowledges does he already have? (See Chapter 10, concerning the influence of selection standards on the requirements for training.)

Only when we have good answers to these basic questions are we in a position to determine in a rational fashion the training characteristics that a training device should be designed to furnish.

Classes of Training Objectives

It is important to distinguish among different classes of things that trainees may need to learn because some of the requirements for effective training devices differ for different classes of training needs. Many classifications of instructional objectives have been offered. Some of them, such as that of Bloom (1954), are very comprehensive and detailed. For present purposes we shall use a modification of the quite simple classification given in the above-cited report by Gagné and Bolles (1959). (This classification differs slightly from the classification of tasks given in other chapters in discussing job design and proficiency measurement. Nevertheless, referring to some of the examples in Chapters 2, 3, 9, 10 and 13 will help in getting a better idea of some of the specific kinds of tasks that may be encountered.) We shall deal here with five main kinds of training objectives, or things-to-be-learned. These will be distinguished in this chapter in relation to the requirements they pose for effective training devices. The five classes are as follows:

1. Identifying. This means pointing to or locating objects and locations, naming them, or identifying what-goes-with what--either physically or in words or symbols. As will be seen, the latter includes much of what we mean by "facts."

2. Knowing Principles and Relationships. This usually means understanding a statement of relationship--as shown by being able to state, illustrate and recognize its implications. Often this is a statement that tells how a cause produces an effect, or how a result can be predicted from several component factors. It may involve knowing arbitrary rules of contingent procedure: If such and such is observed, do thus and so.

3. Following Procedures. This means knowing how to carry out a set of operations that must be carried out in a rather fixed sequence--such as a preflight check, starting a car, or making a well-defined type of calculation.

4. Making Decisions or Choosing Courses of Action. This usually involves the application of conceptual rules or principles as a basis for making the kinds of decisions that are involved in diagnosing or interpreting complex situations. However,

sometimes it involves perceptual discriminations that are learned or acted on directly without reasoning about them.

5. Performing Skilled Perceptual-Motor Acts. These may be quite simple (using basic hand tools) or quite difficult (manipulating the controls of an airplane or performing a sensitive adjustment that requires precise timing). Often, like identifications, the simpler skills provide necessary steps in more complex tasks that require the following of lengthy procedures.

These five classes of training objectives are discussed in the next section in terms of examples related to the kinds of training-device characteristics that are most important for each class. A sixth kind of training objective, development of attitudes and motivation, will be considered later.

Training Devices Considered in Relation to Training Objectives

Use of Illustrative Devices: In the following sections a number of training devices are illustrated and described. The purposes of describing these devices is to illustrate useful principles of device design. This is done by identifying functional characteristics, indicating principles of design, or describing features of construction which implement these principles. Some of the devices are particularly designed for attaining one of the five classes of training objectives distinguished above. Others are designed less specifically and may be used for several of these training goals. The latter are sometimes more adaptable, but often are less well-suited for pinpointing the requirements needed to attain any one particular kind of objective.

"Part-Task Trainers": One of the problems which occurs frequently in the design of training devices is the question of "whole task" versus "part task" training. The general issue is whether it is necessary to have a piece of training equipment that provides for practice of all elements of a task, or whether certain aspects can be selected and practiced independently one at a time. When the latter is appropriate, lowered cost and increased efficiency in training can often be achieved. Often the operational equipment, or a training device that affords simulation of the entire task, may be required during terminal stages of training. But much time in the use of such devices can be saved, and the number of devices required consequently reduced, if those elements of the task that do not require the total equipment are first mastered on simpler equipment.

Some of the prerequisite knowledges and skills needed for identification and following of procedures can nearly always be separated out from the total requirements of a position, and learned more effectively and more economically with "part-task" training devices. Furthermore, in training procedural sequences those subtasks that are confined to a single portion of the equipment should often be learned with part-task training devices. This is particularly true of those that do not require real or simulated feedback from the total system.

Sometimes, however, two kinds of abilities, such as identifications and procedures, can efficiently be learned concurrently. A good example is in the case of sound-film demonstrations of procedures. If properly designed and used, a film could teach the identifications of parts and procedures for using them at the same time, by appropriate pointing and naming of each element at the time when it is introduced into the procedural sequence. Similarly, a device designed to teach one-to-one correspondences can also be used to teach knowledge of relationships, since "knowing" a relationship, at least at an elementary level, often becomes identical with identifying the terms that are required by the relationship.

A detailed account of considerations entering into the rationale and specific design features of part task trainers is given by Miller (1956e). A discussion of some pertinent considerations applying to part task trainers as well as other problems in the design of simulators and related devices is presented by Gagné (1954) from the standpoint of the research issues they pose. See also Adams (1959).

Individual Versus Class-Group Instruction

For training in manual skills and, to some extent, for instruction in decision making and following of procedures, individual supervised practice is often recognized as very important. This is less well-recognized in the case of teaching identifications and principles, where the group lecture method is very commonly employed.

However, the teaching of identifications and principles can also generally be done more effectively through individual training, though this is sometimes thought to be impractically expensive. When feasible, individual training may be greatly superior to group instruction because of the fact that different students learn at very different rates. Holding all students to the same rate, as must be done in a class group, is thus wasteful and inefficient, even though it is a very common practice. With most class-group instruction, either the slower students do not cover the material or what they fail to get in class must be made up by individual study. The latter is in itself often very inefficient, despite attempts to inculcate efficient study habits.

Furthermore. most group instruction fails to provide opportunity for a sufficient amount of active, guided student practice or recitation. This is one of the most important factors in effective learning, because it provides the opportunity for detecting errors, misconceptions, or inadequate mastery of each portion of a subject, and for correcting these deficiencies before the student goes on to new material.

Devices and methods that can be used for both individual and group instruction are illustrated in the following sections. Particular aspects of the general disadvantages of group instruction are noted in relation to specific classes of training objectives. The feasibility of using individual instruction to replace less efficient methods of group-lecture instruction for achieving various classes of training objectives is increasing because of current progress in the development and use of automated or semi-automated self-instructional devices of the kinds described in Chapter 12.

Summary

1. Design of training devices or procedures should start from a detailed analysis of performance requirements, specific knowledges and skills needed to meet them, and basic characteristics of the trainees.
2. Requirements for training procedures and devices should be oriented as explicitly as possible in terms of specific types of human performances to be attained. In general, these fall into five broad classes: identifying, knowing principles and relationships, following procedures, choosing courses of action, and performing motor skills.
3. The designer of training devices should be alert to the possibility of reducing training-device complexity and cost by use of part-task trainers to teach prerequisite knowledges and skills. However, it is often possible to achieve more than one kind of training objective concurrently in a well-designed device if training objectives have been clearly analyzed.
4. Rather than placing reliance on aids to class-lecture forms of instruction, effort should be made whenever possible to provide devices that permit individual learning, paced to the needs of each student and providing a maximum of active, guided student response and prompt correction of errors. Self-instructional devices described in the next chapter can increase the feasibility of doing this.

Types of Training Devices Particularly Suitable for Various Classes of Training Objectives

Teaching Students to Identify Things

Basic Requirements: The prevalence and importance of the kinds of learning which devices in this category are designed to meet has been well described by Gagné and Bolles (1959), as follows:

> "The learning of identifications is one of the most common things a human being does, from early childhood throughout his adult life. Although this type of learning is common to nearly all jobs, its importance can easily be overlooked. For example . . . many jobs require the identification of hundreds of faces, places, tools, or materials, and in such instances the period of learning, or training, becomes an essential requirement.
>
> "In the military services, with their frequently changing jobs or parts of jobs occasioned by the introduction of new weapons, the learning of new sets of identifications is a ubiquitous phenomenon. The pilot who learns to operate a new aircraft must first learn to identify the controls and instruments of the new cockpit. The observer has to learn to identify targets from radar returns. The electronic technician who is being trained to maintain a new guidance system must first master the identification of its parts and their locations, as well as their symbols on schematic diagrams. The supply man who is most highly skilled is the one who can identify perhaps thousands of components and parts, and their bin locations, without going through the laborious process of tracing them down by nomenclature through a succession of technical orders."

Suitable Devices and Methods: The group lecture method for teaching identifications (or, at least, for presenting them and hoping they will be learned) is frequently employed. Where the identifications refer to equipment or locations or other readily visualized things, it is common practice to accompany the lecture by some form of "teaching aid" or so-called training device. This may be the actual equipment or situation (see Figure 11-1), or it may be a cheaper substitute in the form of pictures, charts, slides, models, etc. Characteristics of these kinds of devices and their uses are considered further in a later section of this chapter.

A special disadvantage of the lecture method for identification learning is that it generally fails to take adequate account of necessary conditions for efficiently learning the large number of identifications that may need to be mastered. Often these identifications are merely stated and pointed out by the instructor, whereas effective learning requires active response in the form of repeated drill or recitation, by each student on each identification until it is mastered.

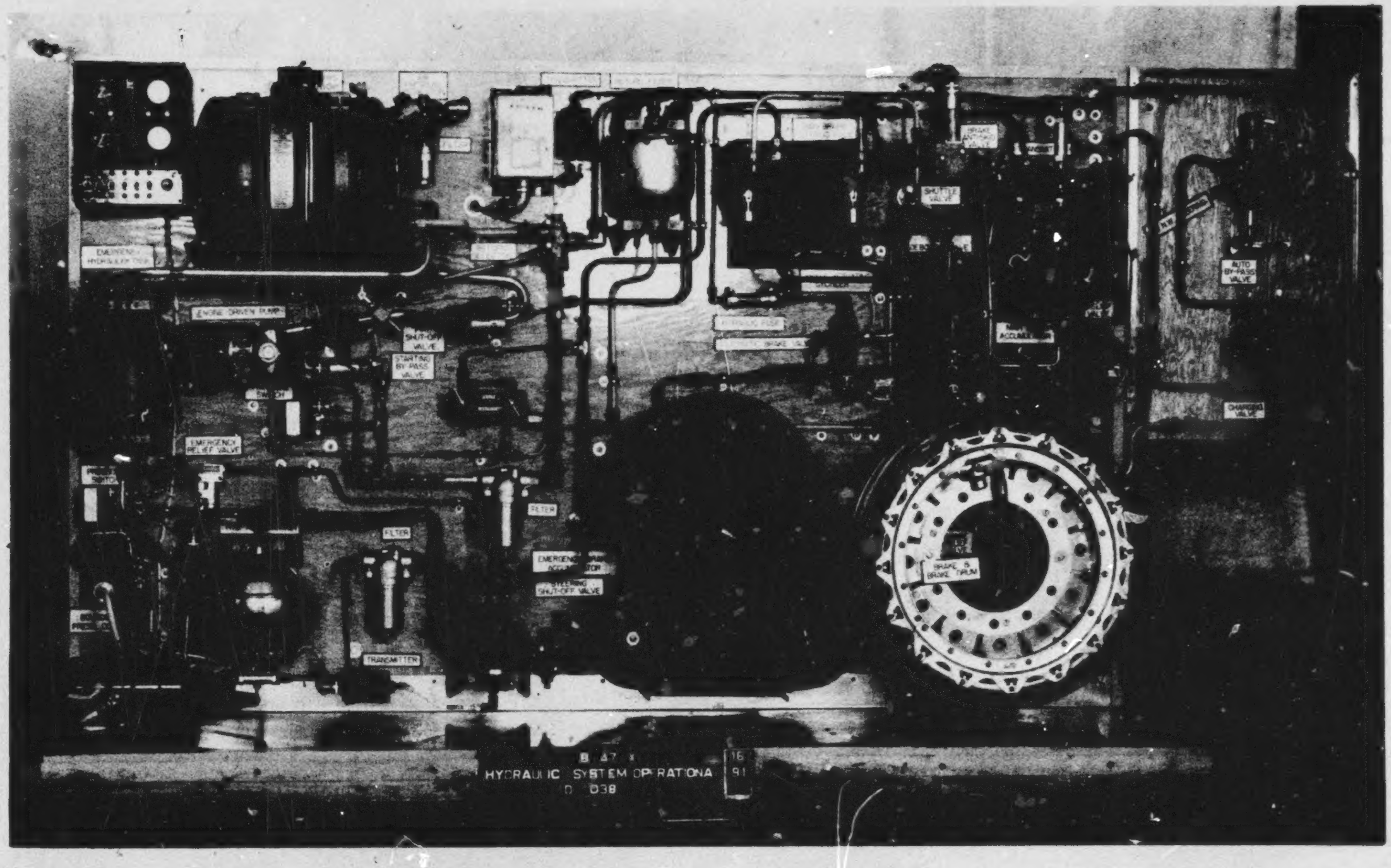

ENGINE DRIVEN PUMP
SHUT-OFF VALVE
STARTING BY-PASS VALVE
SWITCH
EMERGENCY RELIEF VALVE
FILTER
FILTER
TRANSMITTER
STEERING SHUT-OFF VALVE
SHUTTLE VALVE
BRAKE & BRAKE DRUM
AUTO BY-PASS VALVE
CHARGING VALVE
B 47
HYDRAULIC SYSTEM OPERATIONA
D 038
16
91

Figure 11-1. A Representative Equipment Subsystem Mock-up. Equipment of this type is widely used in technical schools and by "mobile" or decentralized training units. Actual equipment components are often mounted with accessory equipment so that the set actually "works."

Where group instruction must be used, class drill rather than straight lecturing is the best method of teaching identifications. Relatively simple aids in the form of pictorial charts, flash cards, or slides are usually at least as satisfactory for this purpose as more expensive aids such as mock-ups and models. Sometimes, in fact they are more efficient than mock-ups because, in addition to their lower cost, they provide better depiction and control of the display in guiding the student's perception of objects and locations to be identified. For example, a chart or slide display such as the one shown in Figure 11-2 can be used to teach locations as well as functional and physical interconnections in teaching the identification of system components. On the other hand, a close-up such as the cut-away drawing shown in Figure 11-3 can be used when it is desired to focus attention on fine detail, either for teaching identification of parts or their locations and interrelations. Often this detail could not readily be observed by more than one or two persons at a time in classroom viewing of a cut-away model of the actual equipment.

Instruction in identifications, using such visual aids, can well proceed by a "Socratic" method of question and answer--"Where is the . . .?", "What is this . . .?", "What goes here?", etc. Note that the training aid does not teach in itself; it merely provides the things to be pointed to and asked about by the instructor and identified by the student.

Individual drill is more effective than class-group drill for the reasons noted above, but usual ways of providing for it are very expensive of instructors' time. With an adequate supply of simple, inexpensive training aids such as realistic drawings or suitable photographs (see Figure 11-4) pairing off students to provide coach-and-pupil teams for such drill can be quite effective under suitable supervision. In addition, recent progress in developing methods for "automated" training can be readily applied for affording the kind of individual drill required for effective learning of a large number of identifications required in a variety of jobs (see Chapter 12).

Teaching Facts and Simple Relations Considered as Identification Training: Knowing "facts" often really consists of being able to identify or relate verbal or symbolic terms in one-to-one fashion. Psychologists often term this the learning of "paired associates." The essential facts that "the capital of the state of Pennsylvania is Harrisburg," and so on for the other states, soon reduce to a set of verbal identifications "Pennsylvania--Harrisburg," or vice versa. Similarly, the "fact" that the number for a holding relay in a specified component of an electronic control unit is A-57325 consists, basically, in identifying that number as the one to specify for obtaining that particular part, or the reverse process of knowing that Part No. A-57325 is that particular relay. The two complementary identifications are not identical; a person may be able to make the proper identification in one direction but not in the other. For example, the student may be able to respond promptly and correctly to "What is this?" when the instructor points to a given item in a complex array, though the

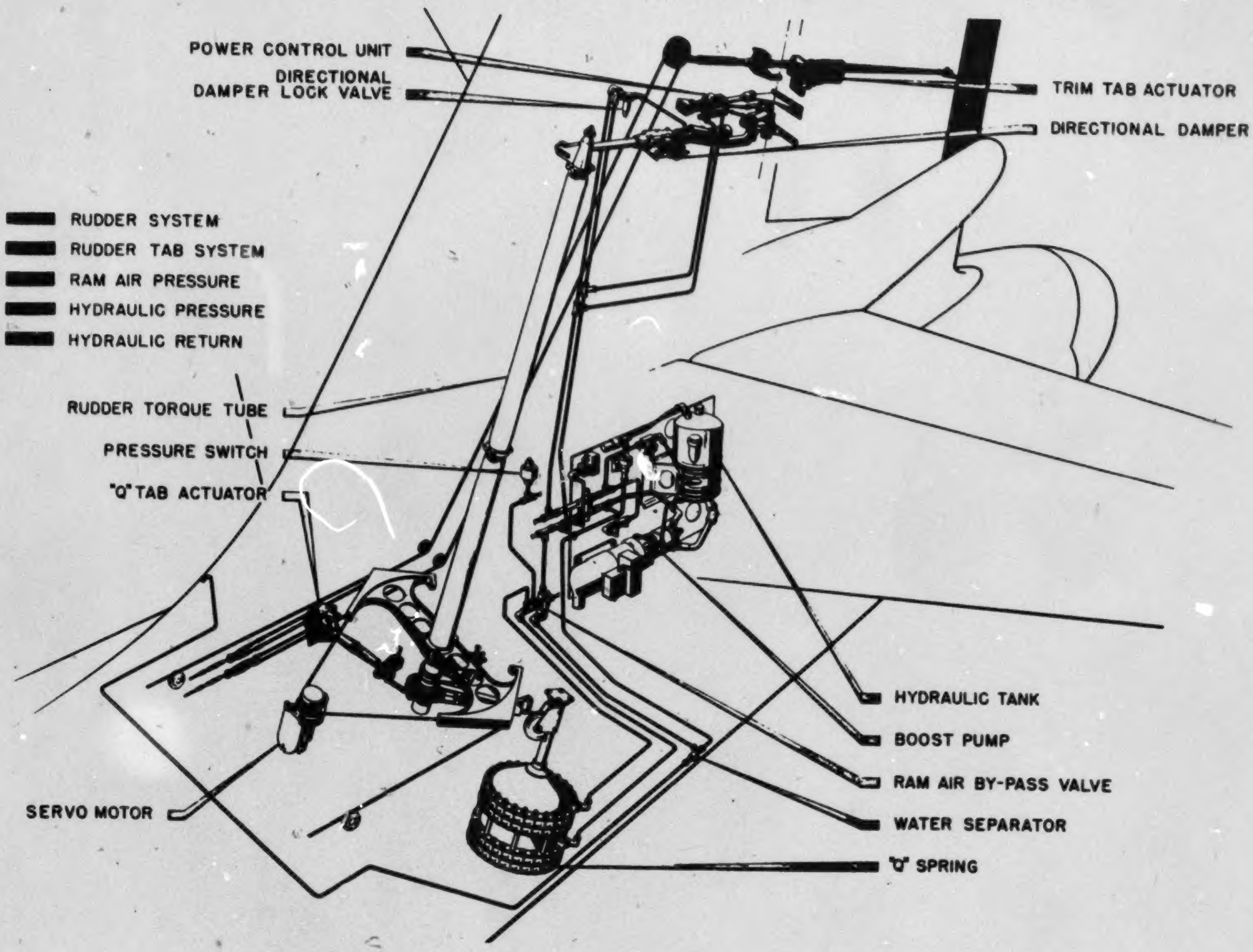

POWER CONTROL UNIT
DIRECTIONAL DAMPER LOCK VALVE
TRIM TAB ACTUATOR
DIRECTIONAL DAMPER
RUDDER SYSTEM
RUDDER TAB SYSTEM
RAM AIR PRESSURE
HYDRAULIC PRESSURE
HYDRAULIC RETURN
RUDDER TORQUE TUBE
PRESSURE SWITCH
"Q" TAB ACTUATOR
SERVO MOTOR
HYDRAULIC TANK
BOOST PUMP
RAM AIR BY-PASS VALVE
WATER SEPARATOR
"Q" SPRING

Figure 11-2. Training Aid Diagram. This provides a basis for combining the learning of component appearances with their locations and interconnections in actual equipment, difficult to display in mock-ups that use actual components.

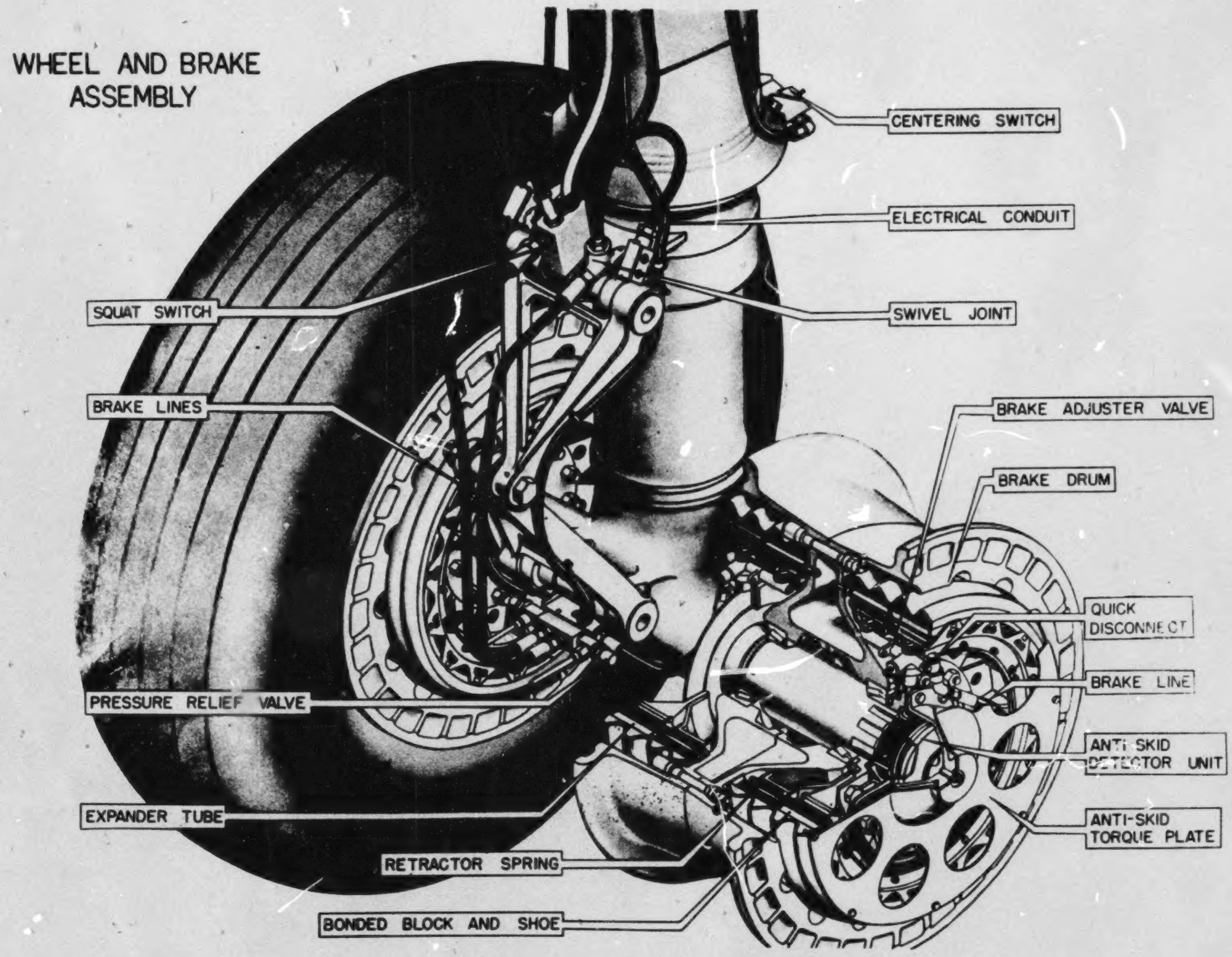

WHEEL AND BRAKE ASSEMBLY
CENTERING SWITCH
ELECTRICAL CONDUIT
SQUAT SWITCH
SWIVEL JOINT
BRAKE LINES
BRAKE ADJUSTER VALVE
BRAKE DRUM
QUICK DISCONNECT
BRAKE LINE
PRESSURE RELIEF VALVE
ANTI-SKID DETECTOR UNIT
EXPANDER TUBE
ANTI-SKID TORQUE PLATE
RETRACTOR SPRING
BONDED BLOCK AND SHOE

Figure 11-3. Enlarged Cut-away Chart. For many aspects of training including identification of components and tracing explanation of functions, such a chart, which can be cheaply reproduced, may be more satisfactory than an actual equipment cut-away.

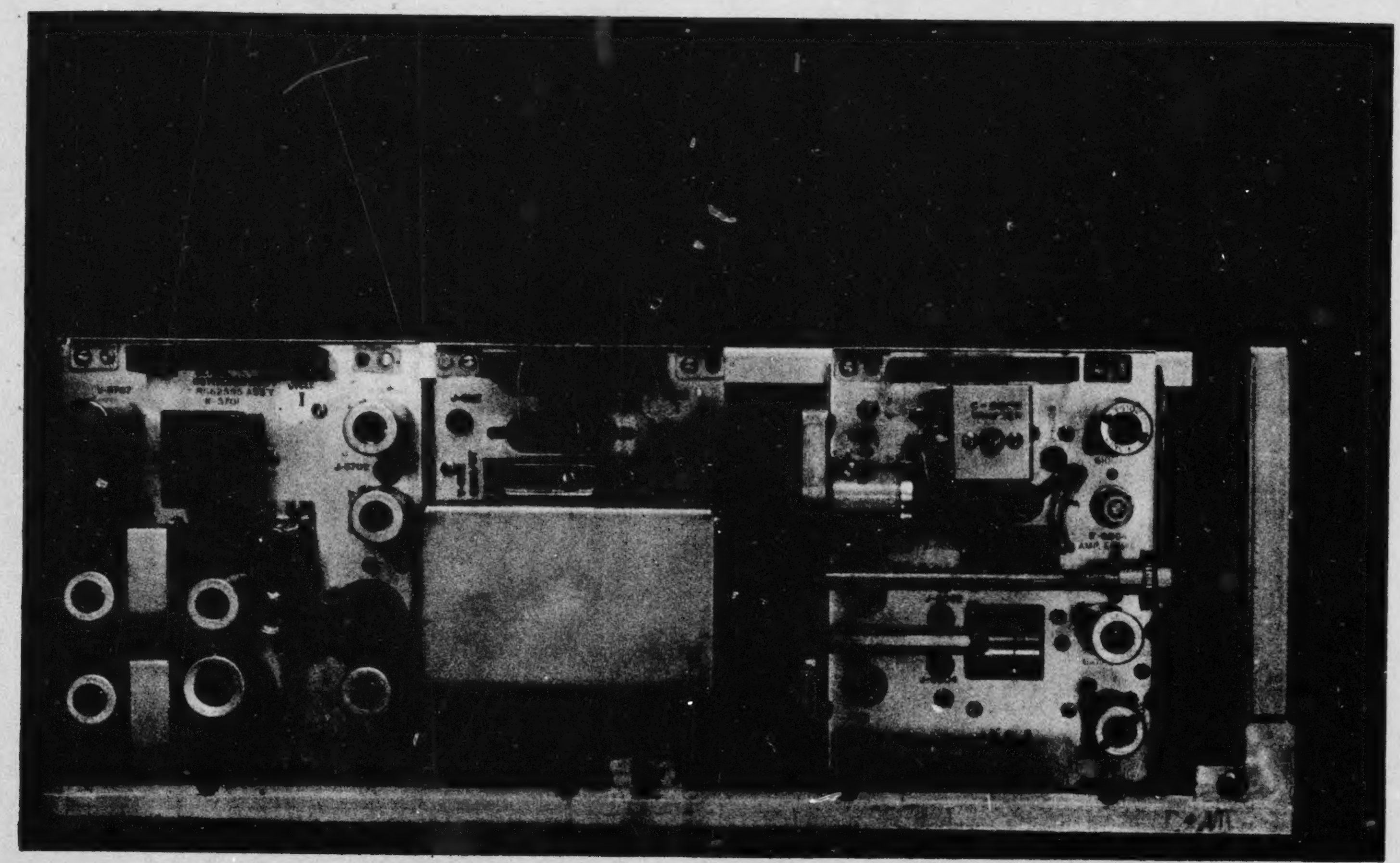


Figure 11-4. A Removable Equipment Component in a Complex System. For training in identification, and many aspects of procedure, a single component, complete or partially fabricated, may be used as a training device instead of the whole system. For many purposes, a set of photographs will suffice almost equally well. For additional realism in locating components, photographs can be mounted on sides of, or cardboard panels within, a "lifesize" box.

same student has not yet learned to locate the item correctly in response to "Which is the ------ (name of item)?"

Training Aids for Effective Identification Drill: Individual or group drill in teaching such identification facts thus needs to provide for practice in making associations in both directions, and training aids should be designed to make this possible. Labeled photographs for initial familiarization should be supplemented by unlabeled ones coupled with lists of terms to be identified on the latter. Where coach and pupil teaching is to be used using students in the coaching role, a labeled aid for the coach and an unlabeled one for the pupil should be provided.

Learning of Principles and Relationships

Basic Requirements: The most important consideration underlying the design of effective devices for this aspect of training is to make a searching analysis of what principles, concepts and relationships are really essential from the standpoint of carrying out the task which the student is being trained to perform. One of the most frequent sources of confusion is that of failing to distinguish between physical principles governing the construction and functioning of a piece of equipment, versus those principles related to its operation and maintenance which the operator or technician for that piece of equipment actually needs to use in performing his job. These are not necessarily at all the same principles, although there might obviously be considerable overlap in many instances.

One of the seemingly obvious sets of principles that may be stressed in training electronic maintenance technicians, for example, are those involving the theory of physical functioning of thermionic vacuum tubes, semi-conductors, electro-magnetic induction, and the like. The principles that are more pertinent to actual job operations, on the other hand, may be principles of data-flow analysis that are independent of how the "innards" of the equipment work. These may tell, for example, how to devise strategies for troubleshooting that effectively take into account the likelihood of various kinds of malfunctions and the time needed for making various kinds of diagnostic checks.

The determination of principles to be taught and the sequence in which they should be taught should, in general, always be based on as complete as possible an analysis of the actual duties that the person being trained will be called upon to perform. The principles of physical functioning of a piece of equipment are unimportant, except insofar as they are actually the relevant principles to apply in making decisions as to alternative courses of action to follow in actual job operations. The determination of the appropriate conceptual content for a particular job--that is, the principles that really need to be applied in carrying it out--often calls for a fairly high degree of skill and experience. Useful guidance is provided in parts of Chapters 2, 3, 9 and 10. The remainder of this section deals with characteristics of devices that may be effectively used for teaching the concepts and principles which have been identified by an appropriate prior analysis as the ones that need to be learned for a particular job.

Knowledge of Principles: Most principles are stated in verbal form or, in more sophisticated applications, in terms of mathematical symbols. "Knowledge" of a principle may be revealed either in terms of being able to state it (or restate it in various forms and contexts), or being able to apply it to a variety of situations. "Knowing" the formulas for computing centrifugal force and the area of a circle so that they can be applied in rote or straightforward fashion are closely similar to tasks of simple verbal identification. On the other hand, knowing how to select the right principle or relationship from a large number of possible ones is often more closely akin to the tasks of problem solving and complex decision making.

Our psychological knowledge of the nature of "understanding" is at present quite incomplete. However, it is clear that mastery of any principle, in the sense of being able to apply it, requires two things. The first is mastery of component identifications (definitions, etc.). The second is extensive practice in mental or verbal manipulation of the terms entering into the principle, and of ways of applying it in diverse situations. Understanding a principle certainly does not mean merely being able to state it in parrot-like fashion in some one particular manner in which it has been memorized. The ability to use a principle generally requires that the basic relationship it expresses can be expressed in variant forms and that the proper elements entering into it can be identified in a variety of instances.

Teaching of Principles: The learning of concepts and principles as applied to a specific operational situation or a piece of operational equipment is perhaps most frequently accomplished by a combination of lecture (or "lecture-demonstration") and unsupervised individual study from training manuals and technical orders. Often such instruction is very inefficient because of inherent limitations of the methods employed. Neither the lecture nor the individual study provides for effective drill and quizzing on the knowledge of the material that is presumably being taught.

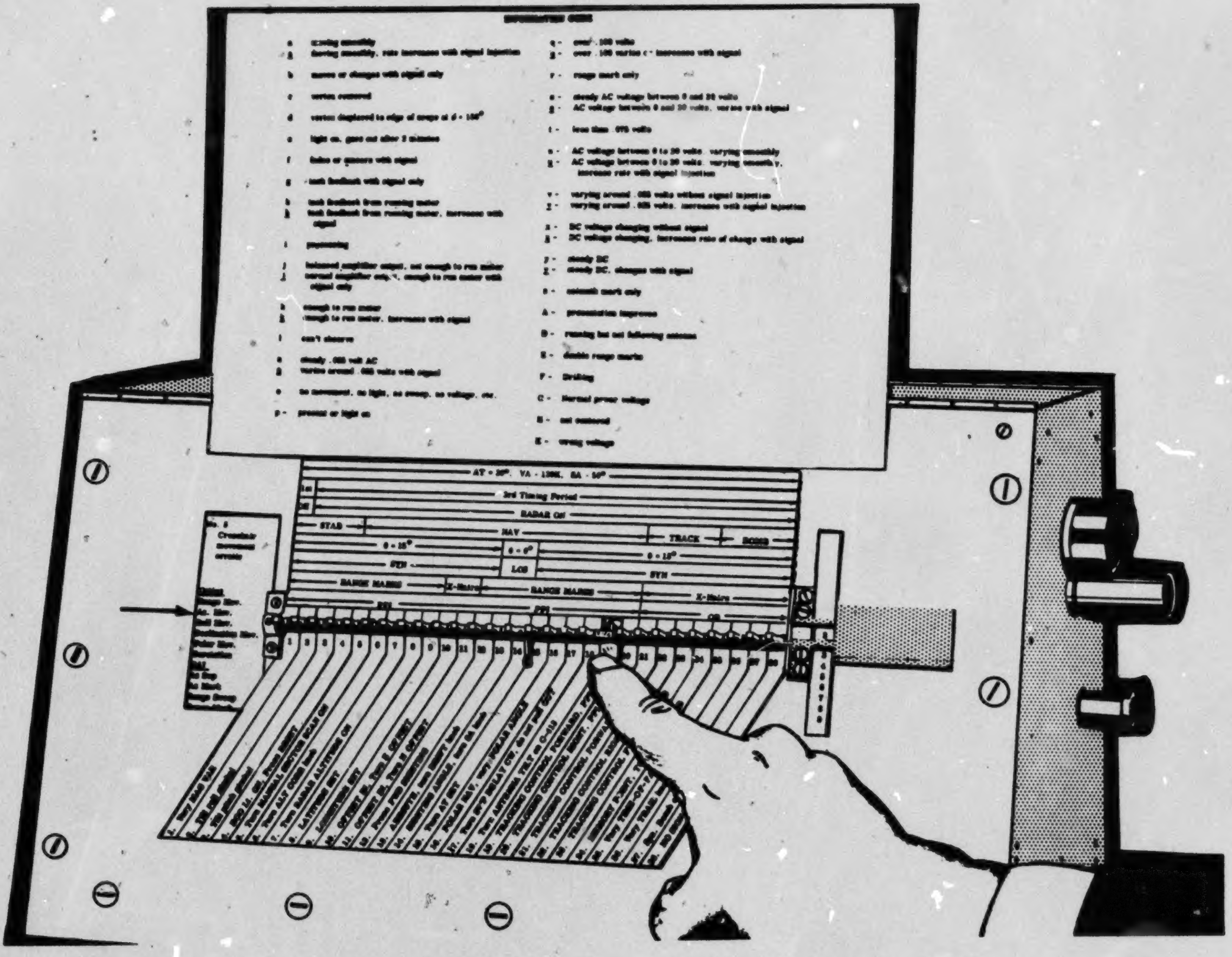
The usual lecture for teaching of principles presents material at a rate much too rapid for it to be really mastered by most of the students. Also, it often presents a hodge-podge of material that fails to differentiate those aspects of the topic that really need to be mastered from those on which general background and familiarity is needed. For the latter, a good film or a lecture with suitable visual aids (see section below) may be adequate. But for those principles that the student needs to master and be able to apply on the job there is probably no substitute for extensive, active practice in dealing with the principles and their application. This often needs to cover a wide range, from learning basic relationships (where the kinds of drill described in the section on "Teaching Students to Identify Things" above, is applicable) to active practice in applying principles to the solution of operational exercises using devices of the kind described in the subsequent section on "Synthetic Practice Devices for Complex Systems."

Between these two extremes, it is often useful to provide the student with extensive practice in verbal manipulation of terms and relationships, in a program of instructional exercises in which concepts are gradually built up, starting with the simpler examples that need to be mastered first before he proceeds to more complex problems. Often the content of the kinds of exercises needed is essentially verbal and symbolic in nature. Here, complex training devices are quite inappropriate; what is really needed for effective training is not equipment but, rather, a well-designed set of instructional exercises. However, the presentation of such exercises and the checking of student responses to them can often be effectively mediated by using some of the kinds of self-instructional devices described in the next chapter.

Knowledge of Highly Complex Interrelationships: Understanding the operation in a complex system may require relating a considerable number of observable indications to a very large number of components that comprise the system. The difficulty of learning to do this is often increased because the relationships between observable indicators and the internal functioning of components may be different under different modes of operation. It is difficult, costly, and time consuming to represent all these complex interrelationships through study and experience of the actual operational equipment or operational situation. Accordingly, it is often desirable to represent the components, indicators, and relationships in a simplified schematic or symbolic form. Generally, this is done in quite unsystematic fashion, and a student must then inefficiently "dig out" many of the pertinent relationships for himself each time he needs them.

The importance of providing a more systematic basis for training through appropriate devices and materials is particularly great in the case of learning the complex functional relationships on which successful diagnosis of malfunctions or troubleshooting of complex equipment may depend. In highly complex equipment the number of possible interrelationships that may exist between malfunction conditions, mode or procedure of operation, and output indications at test points is so large that a systematic way of analyzing and presenting this information can be very helpful.

One approach which deserves consideration is indicated by the device portrayed in Figure 11-5. This device, a "Malfunction Information Trainer" or "MIT," is described in more detail by Crowder (1957). It is essentially a device for displaying the complex relationships between control inputs, output indications, and a large number of possible malfunction conditions existing in any of a complex system's several possible modes of operation. Such a device can do two things: First, it can provide symbolic practice in troubleshooting, in which the effects of various test operations or signal injection procedures can be observed in terms of a variety of output


AT = 30°, VA - 130K, SA - 50°
3rd Timing Period
RADAR ON
STAB
NAV
TRACK
BOMB
θ = 15°
θ = 0°
θ = 15°
SYN
LOS
SYN
RANGE MARKS
X-Hairs
RANGE MARKS
X-Hairs
PPI
PPI
ON
1
2
3
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5
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Figure 11-5. A Malfunction Information Device.

indications, under a wide range of malfunction conditions. Second, it provides a complete, compact, and systematic tabulation, interrelating these factors, which is helpful either as a job aid or as a basis for designing training exercises.

As exemplified in the case of one of the Sperry K-series bomb navigation systems, the device consists of a rectangular table of 28 columns and 478 rows. In the device in Figure 11-5, this table is carried on a roll of paper, and entries for only one row at a time can be examined. The 28 columns represent 28 different critical combinations of control settings and manipulations. These are arranged across the table and are described in abbreviated form in the 28 columns on the panel of the exposure device. Each of the 478 rows is identified as a "test point" or output indicator. The row of the table that is lined up at any one time in the exposure device will display the results of any selected signal-injection procedure on the indications observable at that one test point. Selecting the button for any column of the table will then display, in coded form, the test result that would appear at that test point (row) as a result of the specified control manipulation or signal injection procedure (column). The test result is expressed as a single code letter, such as the letter "b" that has been exposed in column 19 in Figure 11-5.

For this particular system the code used (displayed at the upper part of Figure 11-5) required almost all the upper and lower case letters. A complete table of 3,384 entries was used to reflect the state of the system, in terms of all indications for all indicator points, under normal operation. Additional, similar tables were then constructed for each of a large number of malfunction conditions. Reference to the appropriate row ("test point") in the table for any given malfunction condition would thus yield the indication obtainable with that malfunction for any selected signal-injection procedure.

Such a painstaking and exhaustive analysis of interrelationships in a complex system not only affords a basis for the particular kind of training device here illustrated, but is of more general interest because it represents a possible major step toward making the diagnosis of complex operating systems more of a science and less of an art. One of the reasons why troubleshooting procedures are often so haphazard (and why, hence, training for them is so difficult to systematize) is that no really comprehensive analysis of this kind has been made. Making such an analysis is a laborious and time-consuming procedure, and generally requires a considerable amount of empirical determination with an actual operating system under normal conditions and with various experimentally inserted malfunctions. However, it is entirely feasible, the most difficult part being the construction of the original normal-operation table. For the K-series systems it was found that, after the description of the normal system was written, the description of a specific malfunction could be written by a skilled man in a few hours or less, and that a library of several hundred malfunctions was thus economically feasible. Such a library affords a valuable foundation for the design of training devices and procedures for teaching methods of malfunction diagnosis. In addition, such a compilation, presented in a simplified form of "malfunction indicator" device, could potentially be of considerable value as an informational job aid. The availability of such reference information in conveniently usable form on the job might not only increase the efficiency of troubleshooting--even for experienced personnel--but might greatly decrease the amount of training required in order to locate many malfunctions.

Learning Sequential Procedures

Basic Requirements: The general requirements for effective teaching of procedures are fairly simple, even though procedures to which they apply may cover a very wide range of tasks differing greatly in length and complexity. Examples include assembly and disassembly of a piece of mechanism, removal and replacement of components, fueling a missile, setting up a piece of test equipment, taking an inventory, changing a tire, filling out a form. Some procedures (such as checking out a complex electro-mechanical bombing and navigational system) are very lengthy, involving hundreds of steps. It is often useful, both in training and in job operations, to break down such lengthy procedures into a series of shorter sequences. "Knowing how" to perform a procedure of any length involves knowing how to perform each smallest step (which may resolve into a component identification or a single skilled motor act), linking these together into sets or sequences, and finally integrating these sets into the total procedure.

The learning of a sequence of steps, as distinct from knowing how to perform the individual steps of the sequences, can often be simplified greatly by use of a check list or other job aid (see Chapter 7). For some kinds of procedures, where the steps must be performed rapidly under pressure, it is not possible to "look them up" in such a guide. But where it is feasible to use such a reference source as a check list, the training requirement for satisfactory job performance may be greatly reduced (even though the "old hand" may no longer need the check list).

Knowing what kinds of procedural guides (check lists, etc.) will be available thus is an important determiner of the specifications or characteristics required for a training program or training device. Conversely, an apparently difficult training requirement can often be greatly simplified by converting the requirement so that it calls for a better source of readily-used on-the-job information, which then need not be "stored in the trainee's head." This is particularly true for lengthy, fixed sequential procedures, but may apply also to the requirements for variable or contingent procedures like troubleshooting. In either case, the result of requiring that training equip the man to do the job with the hlep of a well-designed job aid can mean that the training requirements are made much easier: Instead of having to memorize a very lengthy sequence (fixed or contingent), the trainee need only learn a variety of relatively short, unitary procedures which can be called out or "assembled" in proper order on the job by following the sequences given in the job aid.

Training devices for teaching of either lengthy or relatively short procedural sequences generally involve two distinguishable elements. The first is a stimulus input element or source of procedural instructions. The second is a response element or set of "manipulanda" on which the procedures are executed. The source of procedural information may be quite sketchy, merely outlining the steps as in a check list, or may be very detailed and complete, as in a step-by-step procedural-demonstration sound film. The response elements generally consist of equipment and sometimes tools. The equipment can be a real piece of complex operational gear, a model or picture of this equipment, or, at the other extreme, merely a form to be filled out.

Step-by-Step Directions in Teaching of Procedures: Sometimes the input information in a training situation is provided by an instructor who gives the trainee step-by-step directions which the student follows. This has advantages of flexibility and permits individual pacing and adjustment to fit the student's aptitude and rate of progress. However, it is extremely costly of instructors' time. Accordingly, various fully or partially automated substitutes have been devised that will undoubtedly be more and more widely used in the future.

For many kinds of tasks at early stages of training, visual demonstration accompanied by oral directions or explanation is preferable to reliance on purely verbal directions as a guide to initial following of procedures by the trainee. Sound motion pictures have great potential for this purpose. However, their effective use requires that they be constructed specifically as procedural guides, and exclude "familiarization" or "motivational" material which, while appropriate for other purposes, is extraneous to the procedural demonstration. The latter must cover in careful detail each of the steps in the demonstration sequence that are essential if a novice is really to be able to "follow" or successfully imitate the procedures demonstrated. Such films, consisting merely in clear delineation of a series of procedural steps, should have adequate provision for stopping, to allow trainee practice, after each step. They can nearly always be filmed at very low cost, using minimal production facilities. Some excellent guidelines for local production of such low cost films are given by Greenhill (1955).

Effective Use of Procedural Films: For effective use of such step-by-step procedural demonstration films, each student should be equipped with the appropriate response equipment or "manipulanda" for following the procedure. A short demonstration segment is shown, then the projector is stopped on "still frame" while the students perform that task before going on to the next. The instructor can check the students' performance as often as necessary. Such a technique has been used successfully for experimental instruction in the photographic school at Lowry Air Force Base in teaching students to assemble and service Air Force cameras.

The use of step-by-step procedural demonstration films in this manner is greatly superior to the much more common practice of showing a complete demonstration film in a classroom situation and then later having the student try to perform the operations on the basis of recall after a number of minutes, hours or days have elapsed. Convincing evidence on this point has been furnished from data of experimental students by Maccoby and Sheffield (1958). These investigators found that learning was much more rapid when very short demonstration segments of only a few seconds were immediately followed, for at least the first few times through a procedure, by student performance of the steps demonstrated--as compared with conditions in which the practice was deferred even a few minutes (until the end of a relatively short film).

Further techniques for optimizing the use of demonstration film are discussed in connection with the automated self-instructional devices described in Chapter 12.

Training Equipment for Practicing Procedures: For effective practice of procedures the student needs to have an opportunity to make appropriate responses to the step-by-step sequence of instructions that outline the procedure, regardless of whether these are given by a manual, an instructor, or a demonstrational film. There is some evidence that "mental" rehearsal of the motor acts involved in a procedure can sometimes be quite helpful (see Harby, 1952). Generally speaking, however, the practice of procedures should be conducted with the student actively executing the procedures as directed, using appropriate manipulanda in the form of equipment or substitute equipment and any tools required.

For many tasks, actual equipment may be used. Often, however, this is not necessary in carrying out an adjustment procedure. With equipment composed of separate black-box subcomponents such as the one shown in Figure 11-4, a single component of the actual equipment may be used. An incomplete component or photographic replica may be satisfactory when the responses are straightforward and already learned as individual units. In this case the steps of the procedure may be complied with, for much of the practice, simply by such substitute responses as positioning a screwdriver and pretending to turn an adjustment screw by about the right amount, or doing a make-believe flip of a photographed toggle switch from up to down, or by simulating the twisting of a dial and indicating orally to what position it would be turned.

A replica allowing only such substitute or symbolic responses would generally not suffice, however, if the "feel" of the response must be learned. At least those elements of the equipment which provide this kind of feedback need to be physically present for most effective practice. But this by no means necessarily requires that all of the insides of the equipment be present in the components that are to be used for training purposes.

Similar considerations apply where the procedure consists of adjustments and settings of control panels. Often, many parts of the procedure can be carried out with only the face of the instrument present. Certain aspects of procedure, however, will require learning to adjust the steps taken to changing displays affected by the control settings--such as an oscilloscope pattern. For these, the use of the actual equipment is often simpler than trying to simulate the control action.

However, the portions of a procedure requiring this often comprise only a very small percentage of the steps in a procedure. Thus, a simple "surface" mock-up may be satisfactory for practicing nearly all of the procedural steps, with real equipment being used only when required. This means that the number of items of expensive real equipment required for practice can be reduced by using a single piece for a number of students only at the points where it is primarily required.

Variable and Complex Procedures: In other instances, procedures which must be adjusted to the "feedback" of changes in display resulting from adjustments of controls or other manipulations can be provided more effectively or more cheaply by a simulated procedural training device such as that shown in Figure 11-6. In this device, actual or simulated components or photographic representations are used, depending on the needs of training. Special circuitry is provided for feedback for making displays responsive to control adjustments as in actual equipment. An instructor supervises and checks the student as he performs adjustments and check-out procedures. (This device was developed primarily as an efficient means of testing performance for routine alignments and adjustments, but also can be used as a training device for these tasks; see Briggs and Besnard, 1956 for a more detailed account.) Note that, as in this instance, simulation provided need not be fully realistic in all cases in order to meet the needs for effective training. For example, where the discrimination on the actual equipment is essentially a "go/no-go" decision in terms of the way it is interpreted, a simple on-off indicator such as a light may be substituted in the simulator for a meter reading or other quantitative display. The question of whether special simulator circuitry should be provided in a piece of training equipment is often a complex one. A complete discussion of the factors affecting requirements for sensory feedback in training devices used for teaching how to make procedural adjustments on equipment is beyond the scope of this chapter. Some useful guidelines are provided in reports by R. B. Miller (1953b, 1956a, 1956e).

Part-Task Procedure Trainers: Many lengthy and important but relatively simple procedures are required by flight and maintenance personnel in flying modern aircraft and preparing them for flight. Cockpit procedure trainers (consisting essentially of a complete "life-size" mock-up of the cockpit interior and its displays and controls) are frequently used, especially for the training of flight personnel. The number of displays and controls for such a replica is quite large. Some cockpit procedure trainers carry simulation to such an extent that almost every aspect of the cockpit is duplicated in the procedural trainer, though there is considerable variation in the completeness with which displays are made functional and responsive to the acts of controls.

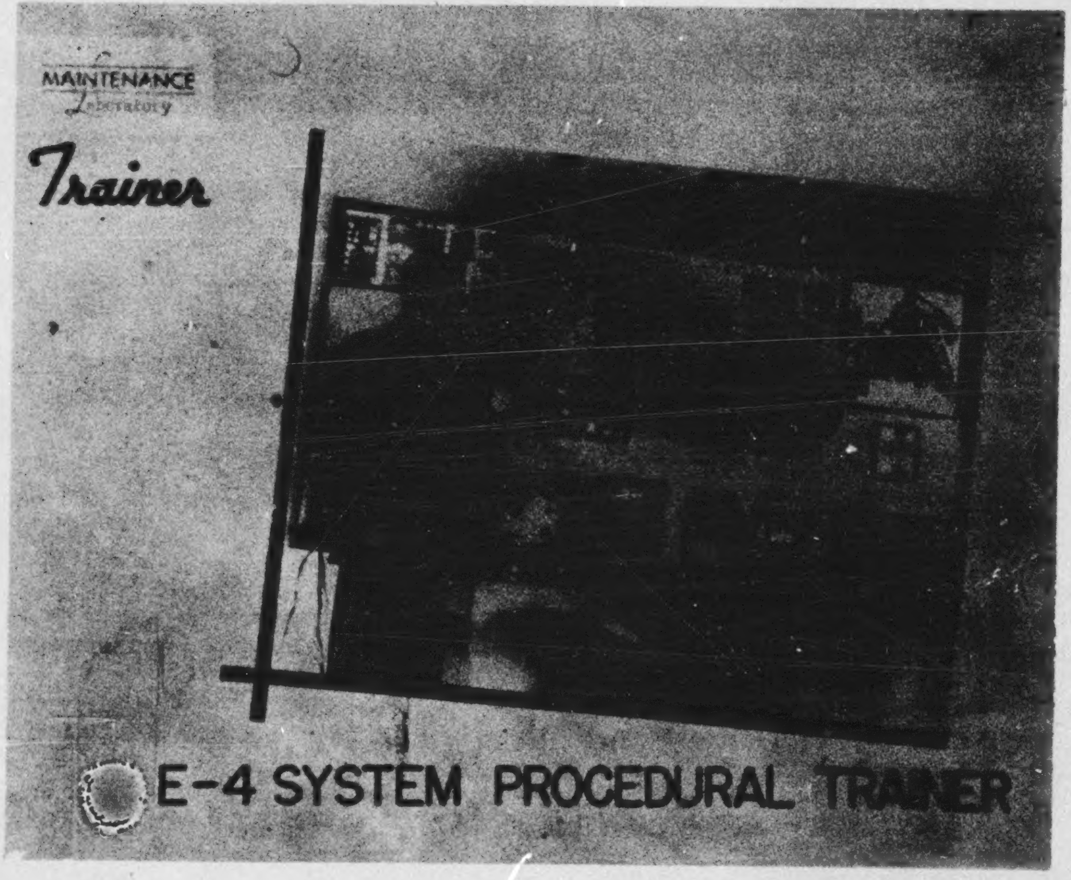
MAINTENANCE Laboratory
Trainer
E-4 SYSTEM PROCEDURAL TRAINER

Figure 11-6. A Special Device for Training of Procedures in Maintaining a Fire Control System.

Such training devices can unquestionably make an important contribution to training, and in many instances can permit a complete run-through of important procedures in a way that is safer or more economical than performing them in the actual aircraft. (The same is, of course, true for panel simulators of consoles used in missile direction and similarly conceived part-task trainers for other kinds of jobs.) On the other hand, many procedures and discriminations which flight personnel and maintenance personnel must learn to accomplish either require only a small portion of the total available display at one time, or require that only a few instruments be made responsive for the actions of controls--with the rest merely furnishing basic information or being irrelevant to that particular procedure.

Accordingly, important economies could sometimes be realized by constructing several part-task trainers. In these the instrumentation can be limited primarily to those display-control combinations that enter into the tasks that require the most extensive practice in order to master. Even as simple a mock-up as that provided by the experimental training device shown in Figure 11-7 might frequently suffice in providing such intensive practice on certain key procedures. (This device is described in an unpublished staff memorandum by L. M. Stolurow and L. P. Pottsepp, "The Propulsion Research Unit Jet Engine Troubleshooting Trainer," prepared at the Maintenance Laboratory of the former Air Force Personnel and Training Research Center.)

The utilization of such a simplified part-task trainer does not necessarily replace the more complex and completely instrumented training device, but rather may be used to supplement it. This can often best be done by using the simpler part-task device to insure mastery of unit skills, reserving the more complex and expensive device for those portions of training for which its characteristics are really required.

In addition to its economic advantages, the simplified trainer may sometimes actually be a more efficient training device than a more complete simulator because it makes for greater concentration on only the crucial aspects of the task during initial stages of learning. Also, the relatively simple part-task trainer makes feasible a program of intensive practice that leads to "overlearning" of crucial operations: The trainee continues practice of a critical procedure until he can practically "do it in his sleep." This may cost too much when more complex devices are used.

Training in Decision Making and Diagnosis

Basic Requirements: "Decision making" and "problem solving" in elementary form include many very simple choices that every child soon learns to make easily and automatically. But learning to make good decisions in complex situations is undoubtedly one of the most difficult problems a trainee has to face. The need is encountered in a great variety of tasks in nearly all phases of military and industrial operations. It will be exemplified in this chapter primarily in relation to the troubleshooting or diagnosis of malfunctions in equipment systems.

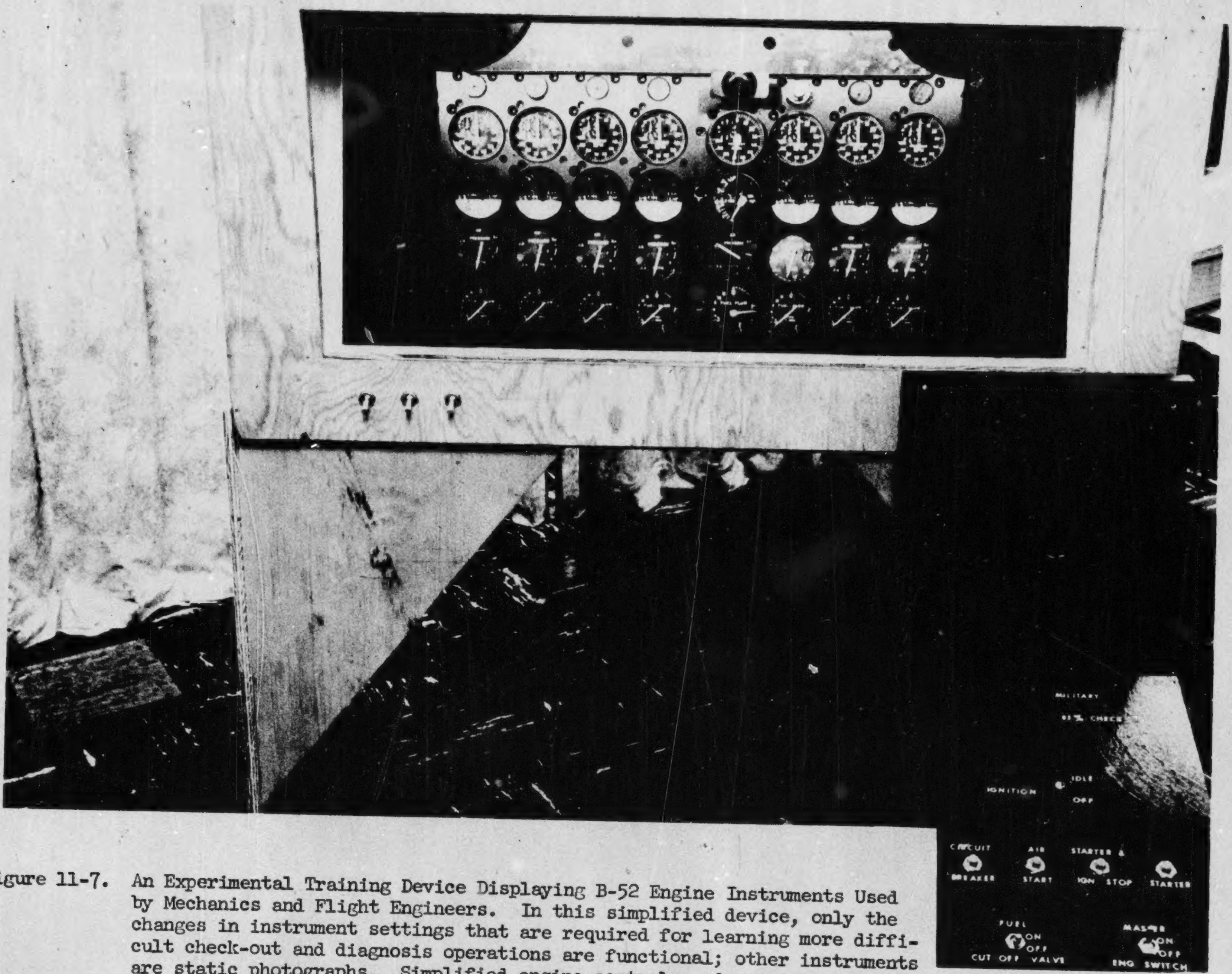
MILITARY
CHECK
IGNITION
IDLE
OFF
CIRCUIT BREAKER
AIR START
STARTER & IGN STOP
STARTER
FUEL
ON
OFF
CUT OFF VALVE
MASTER
ON
OFF
ENG SWITCH

Figure 11-7. An Experimental Training Device Displaying B-52 Engine Instruments Used by Mechanics and Flight Engineers. In this simplified device, only the changes in instrument settings that are required for learning more difficult check-out and diagnosis operations are functional; other instruments are static photographs. Simplified engine controls and special accessory equipment provide intensive practice in difficult aspects of the job.

It is generally felt that the complex processes of diagnosis or other problem-solving tasks cannot be fully mastered simply by routine kinds of practice: Knowledge and understanding of guiding principles and of internal cause-effect relationships often seem to be required. At the same time it is easy to carry this notion too far, and one of the main ways in which training devices can undoubtedly contribute to ability in such tasks as troubleshooting is through providing a wide variety of suitably guided practice or experience in applying methods and principles in the diagnosis of actual or simulated malfunction conditions.

Practice in Troubleshooting: After a student can interpret symptom information and follow appropriate courses of action for making checks, training is required that will give him actual practice in making the decisions involved in choosing alternative courses of action. For a complex system which can have a very large number of possible malfunctions, skill in making such decisions for troubleshooting requires the ability to formulate efficient strategies of diagnosis. This may call for extensive opportunity for practice before satisfactory effectiveness is attained.

The troubleshooting of even an extremely simple system such as an automobile ignition system or a landing-light circuit may pose quite a formidable problem to the novice. For such a simple system, adequate practice in diagnosing artificially inserted malfunctions can be afforded by a fairly simple mock-up, such as the one shown in Figure 11-8, composed of the actual equipment components. However, the mock-up must be designed with this purpose in mind, so that any malfunction can be inserted or readily simulated by appropriate adjustments made by an instructor. Use of simple test equipment such as a continuity checker then permits the student to conduct diagnostic tests to determine the nature of the malfunction. Even with such a simple system, however, the use of practice in using such job aids as a schematic circuit diagram or, better, a proceduralized strategy of step-by-step checks, is generally desirable.

Synthetic Practice Devices for Troubleshooting Complex Systems: When the job requirements are for analyzing malfunctions in equipment of much greater complexity, use of an operational equipment mock-up in this fashion seldom provides a fully satisfactory training device. The necessary malfunctions often cannot feasibly be inserted in such a way as to give the students a full range of practice. Even if they could be, the carrying out of all the actual diagnostic checks that would be required to provide adequate practice in interpreting different patterns of symptoms, and learning to make appropriate decisions based on them, would be prohibitively time consuming.

Requirements are thus posed for a device in which:

1. Essential kinds of interrelations between malfunction conditions and observable indications can be observed and acted upon.

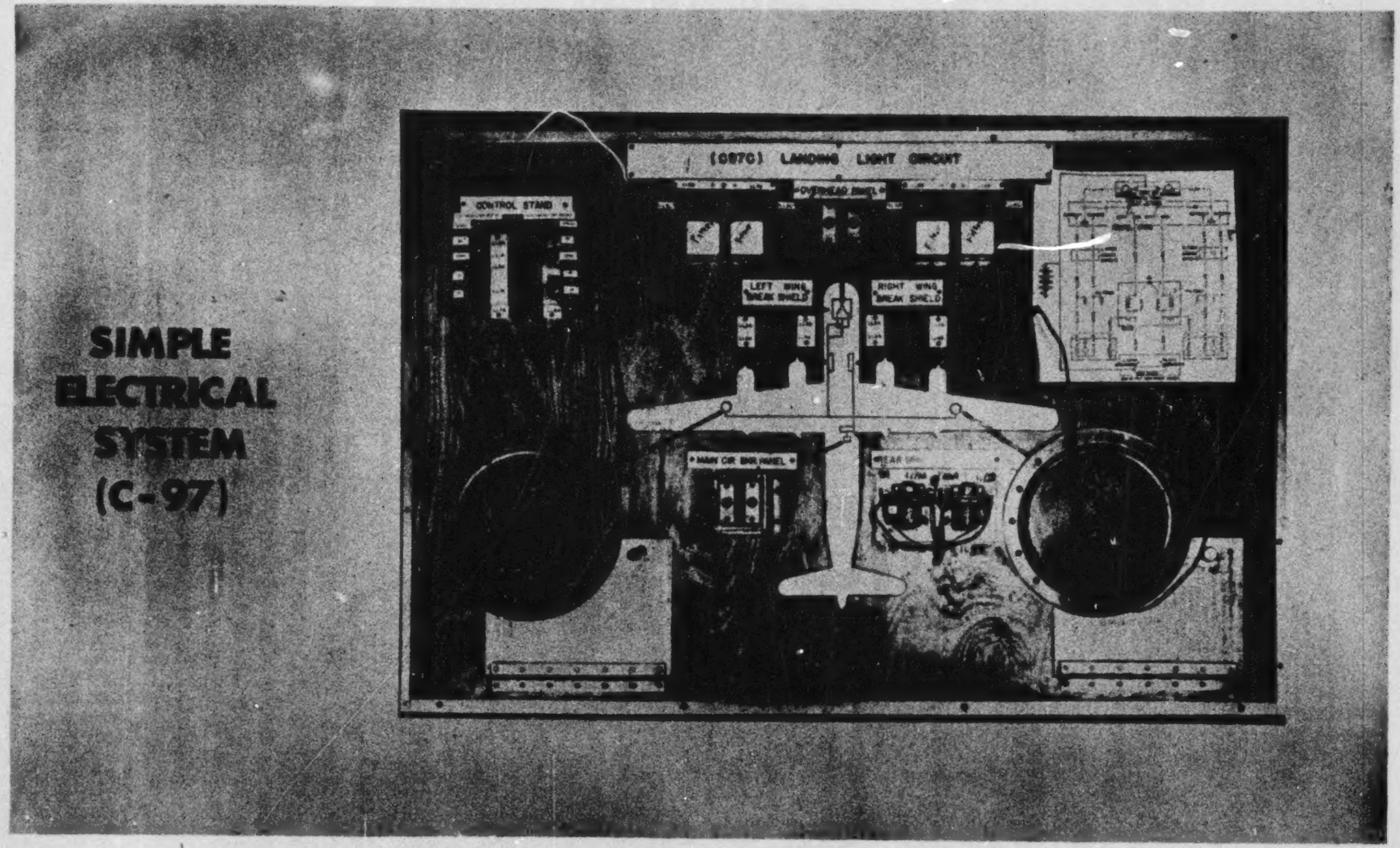
SIMPLE
ELECTRICAL
SYSTEM
(C-97)
CONTROL STAND
(087C) LANDING LIGHT CIRCUIT
OVERHEAD PANEL
LEFT WING BREAK SHIELD
RIGHT WING BREAK SHIELD
MAIN OR BKR PANEL

Figure 11-8. Simple Electrical System Training Panel that can be used both as a demonstration aid and, where circumstances permit, to assist student practice in troubleshooting a simple system.

2. A wide range of malfunctions can be readily inserted in such a way as to produce appropriate symptoms.

3. The cause of these symptoms can be discovered by analysis of data obtained at proper system check points.

4. The procedures required to obtain this information and take corrective action are simplified so that they can be carried out quickly and yield appropriate feedback promptly to the trainee.

The so-called "malfunction and circuitry" trainers (or "MAC") shown in Figures 11-9 and 11-10 were designed as approaches to the requirement for training devices which provide individual troubleshooting practice in a way that meets these requirements for complex systems. In these devices, a wide variety of malfunction conditions can be introduced by the instructor for the student to diagnose, simply by changing plugboard connections and switch settings. The experimental device shown in Figure 11-9 was developed in terms of simplified inputs and indicators that simulate nearly all aspects of the operation and essential circuitry of the K3A bomb navigational system, in a way which would be efficient for training in knowledge of system functioning, data flow, and troubleshooting methods. A detailed description of the design and use of this device is given by French (1956a), and some experimental data on its effectiveness in a training course are presented by French (1956b) and by French, Crowder, and Tucker (1956).

The conclusions of the latter study indicated that some modifications in the design of the device, including more realistic representation of some of the components, controls, and test equipment, could make it a highly effective supplement to the use of the operational equipment either in formal training courses or in job-training situations. The study demonstrated that apprentice mechanics could learn systematic troubleshooting procedures by use of the device under appropriate supervision of an instructor, employing logical analysis of the system's data flow as simulated by the functioning of the training device.

The later model of the "MAC" trainer for the MA-7a bomb navigational system, shown in Figure 11-10, is described by French and Martin (1957). This report summarizes the main advantages of this kind of training device, as well as the specific operation of the particular device illustrated. Functional specifications for a similar trainer are given in a Technical Memorandum by French (1957). In the later model "MAC" trainer various basic control elements of the device (such as the tracking handle) are reproduced realistically, as are test instruments used in performing diagnostic checks. Major replaceable components are represented by small plug-in units. Some of the other components are merely pictorially represented. Most of the indicators of system output are reduced to "go/no-go" indications (represented by indicator lights).

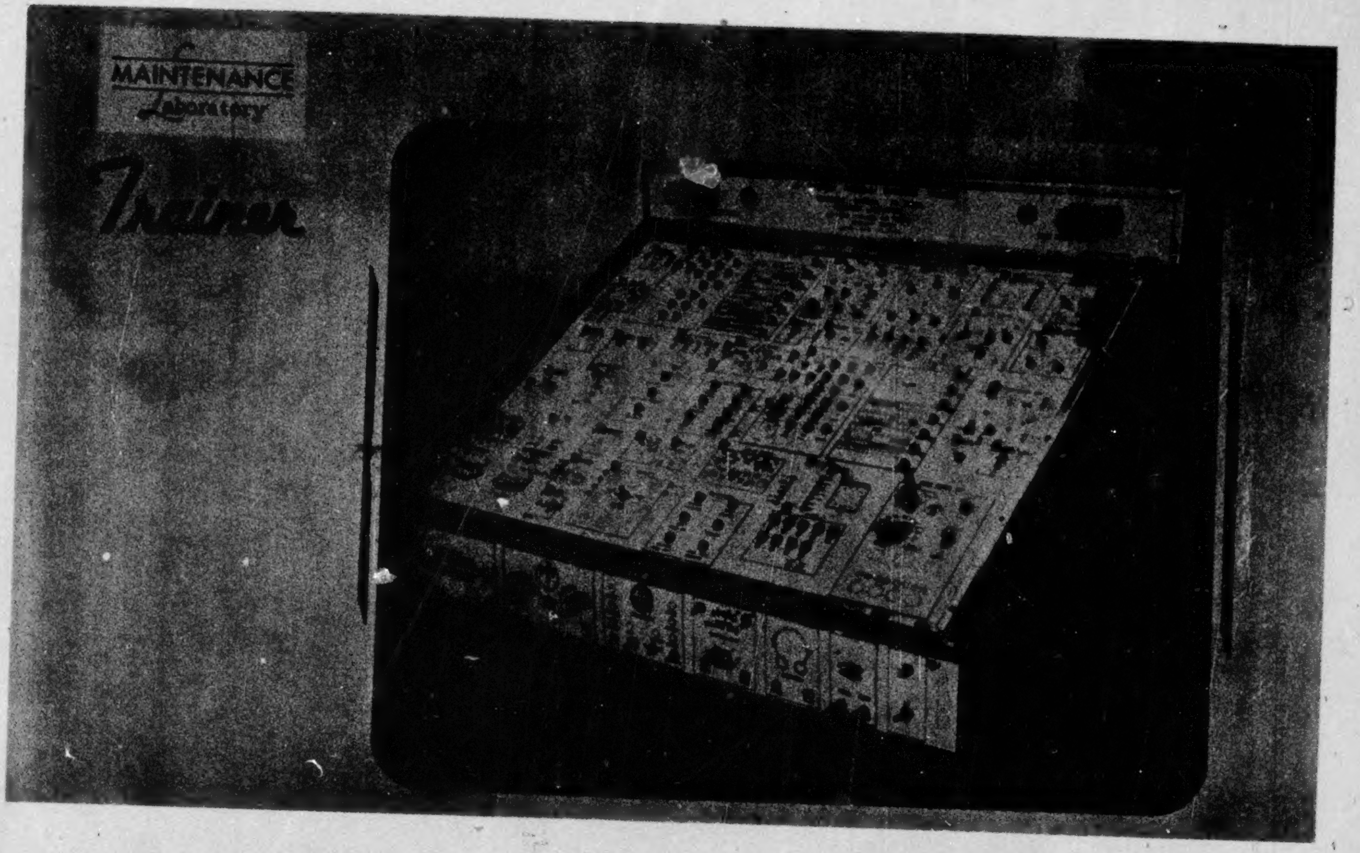

Figure 11-9. A "Malfunction and Circuitry" Training Device that allows practice in any of the skills of troubleshooting. This device is an earlier model of the troubleshooting training device shown in Figure 10. It employs less realistic simulation of displays, controls, and actions required in making tests than the later device.

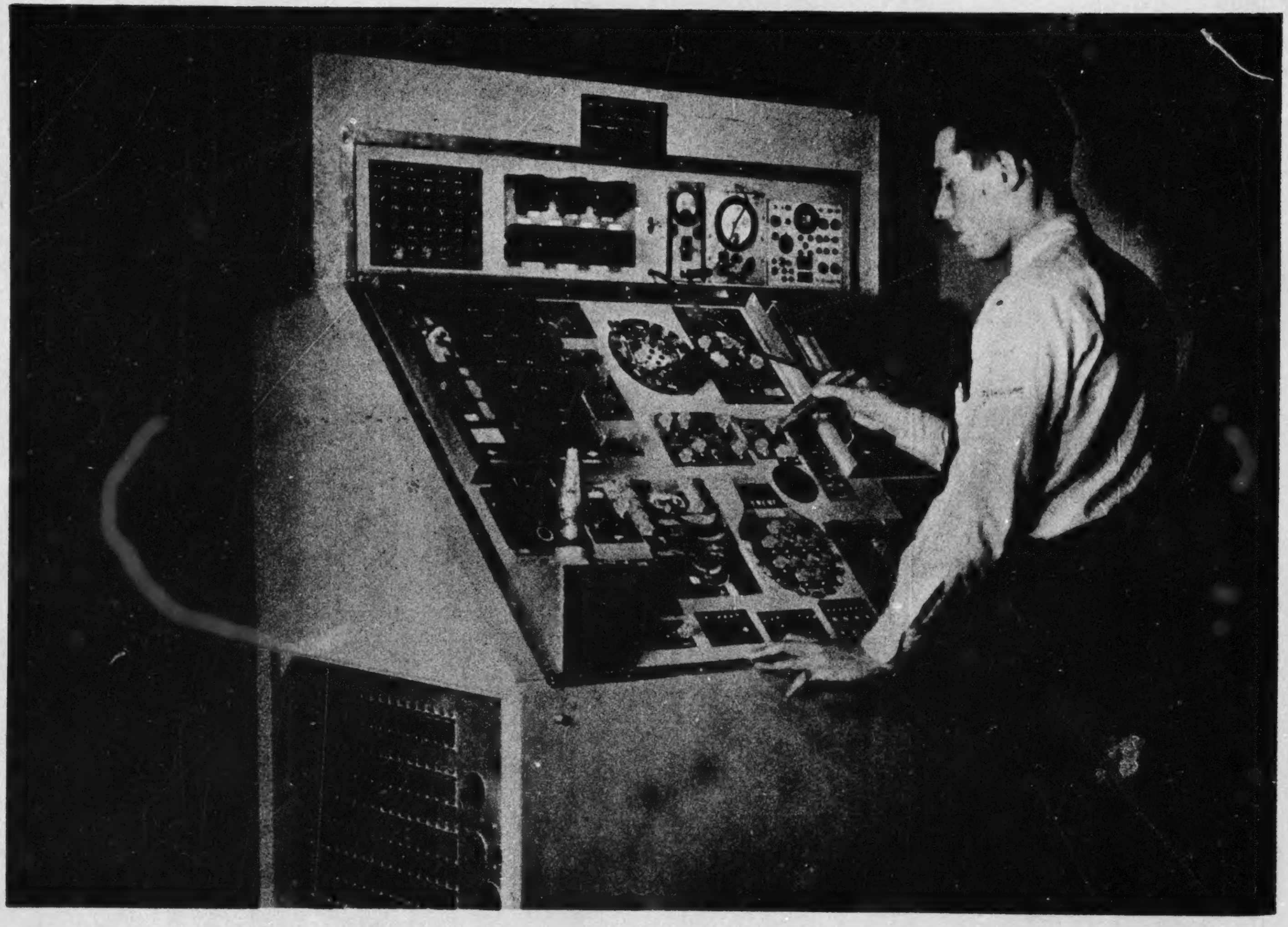

Figure 11-10. The "MAC II" Malfunction and Circuitry Trainer. This device makes possible the concentrated practice of a great variety of malfunction problems in an airborne bombing-navigation system.

The basic advantages and disadvantages of this type of training equipment are summarized by French and Martin (1957). Some of the advantages they point out for the "MAC" trainer, when used to supplement training accomplished on equipment in the aircraft or a bench mock-up, are:

1. A wide variety of malfunctions may be experienced and analyzed in a relatively short period.
2. Training in basic troubleshooting skills may be accomplished without jeopardizing operational commitments.
3. The risk of damaging or seriously misaligning operational equipment is lessened.
4. The controls and indicators of the system are closely integrated, which is particularly advantageous for effective demonstration or practice.
5. A "MAC" trainer costs only a fraction of the amount of the operational system itself, and requires negligible maintenance.

Among the disadvantages or limitations of the "MAC" type trainers are that:

1. Since a "MAC" trainer reduces system operation to a simplified simple level, there is little provision for experience in the interpretation of exact, quantitative readings and visual displays.
2. Certain classes of malfunctions cannot be simulated with the devices thus far constructed.

The "MAC" trainer can therefore be recommended as a highly effective supplement, but not as a complete substitute for the actual equipment in maintenance training programs.

Although such a device as a "MAC" trainer may require a considerable amount of supervision by an instructor at some points, the student is often able to proceed by himself on a "problem solving basis," particularly in more advanced phases of training. Practice on such a device appears to be an excellent means of gaining familiarity with system data flow, circuit analysis, troubleshooting procedures, and the use of job aids such as maintenance manuals. The device thus shares certain features with more completely automated "teaching machines" that are discussed in Chapter 12.

Like the teaching machine, the advantage of such a device over conventional lecture methods lies in the fact that it challenges the student and requires active performance of appropriate responses, with immediate "feedback" as a consequence of the responses which the student makes.

It also has, like many of the teaching machines, a sort of "game-like" quality that unquestionably can contribute to a student's motivation as he tries to "beat" the problem posed by the machine.

System-Linked Versus Multi-System Devices: The "MAC" trainer is an important example of a synthetic trainer that makes considerable use of symbolic representation and simplified indicators and controls, and that is designed and constructed to apply to the training for a particular equipment system. The latter feature, inherent in all system-linked training devices, has the economic and logistic disadvantage that a new trainer must be designed for each new equipment system, and must be modified to reflect major engineering changes in successive models of operational equipment. This not only increases the total cost of training equipment, as compared with what can be achieved with general purpose trainers, but means that considerable "lead time" is required in developing the device. Though this lead time may be much less than would be required in the case of trainers which make extensive use of operational equipment components, it can still be a formidable factor in trying to assure that adequate training equipment is available by the time it is required.

On the other hand, some kinds of training devices are designed to fit the requirements of a general class of training functions common to a number of systems. These may require, for their adaptation to the training of new jobs (e.g., those occasioned by a new equipment system), only the preparation of new materials, in verbal and pictorial form, that can be printed on paper or film. The latter materials normally take much less time to prepare and, particularly, to reproduce in quantity, than is the case with "hardware" configurations for a system-linked trainer such as the "MAC" trainer. On the other hand, it may be difficult to devise a general-purpose trainer which will afford the means of simulating all the aspects of system operation required for effective practice in either the intellectual or procedural aspects of system checkout and malfunction diagnosis.

One solution that has considerable merit is illustrated by the combination of equipment shown in Figure 11-11, described by Briggs (1956). The programming of problem presentation and other information sources, including the results of checks made by the student in the course of practice, are presented in pictorial, numerical or verbal form on the screen of a microfilm device at the right. (This is a modification of an automated device described further in Chapter 12.) It is used in conjunction with a mock-up of actual and simulated system components as in the device at the left in Figure 11-11. The results of manipulations of controls made by the student on the left-hand device may either be fed directly into the programming of the microfilm projector--or, more simply, the sequence of information presented by the latter may be governed by coded inputs to it that are injected by the student or instructor on the basis of the results of manipulations performed with the complementary equipment-component mock-up.

This kind of combination may afford many of the same advantages from the standpoint of training as does the "MAC" trainer and similar devices, but

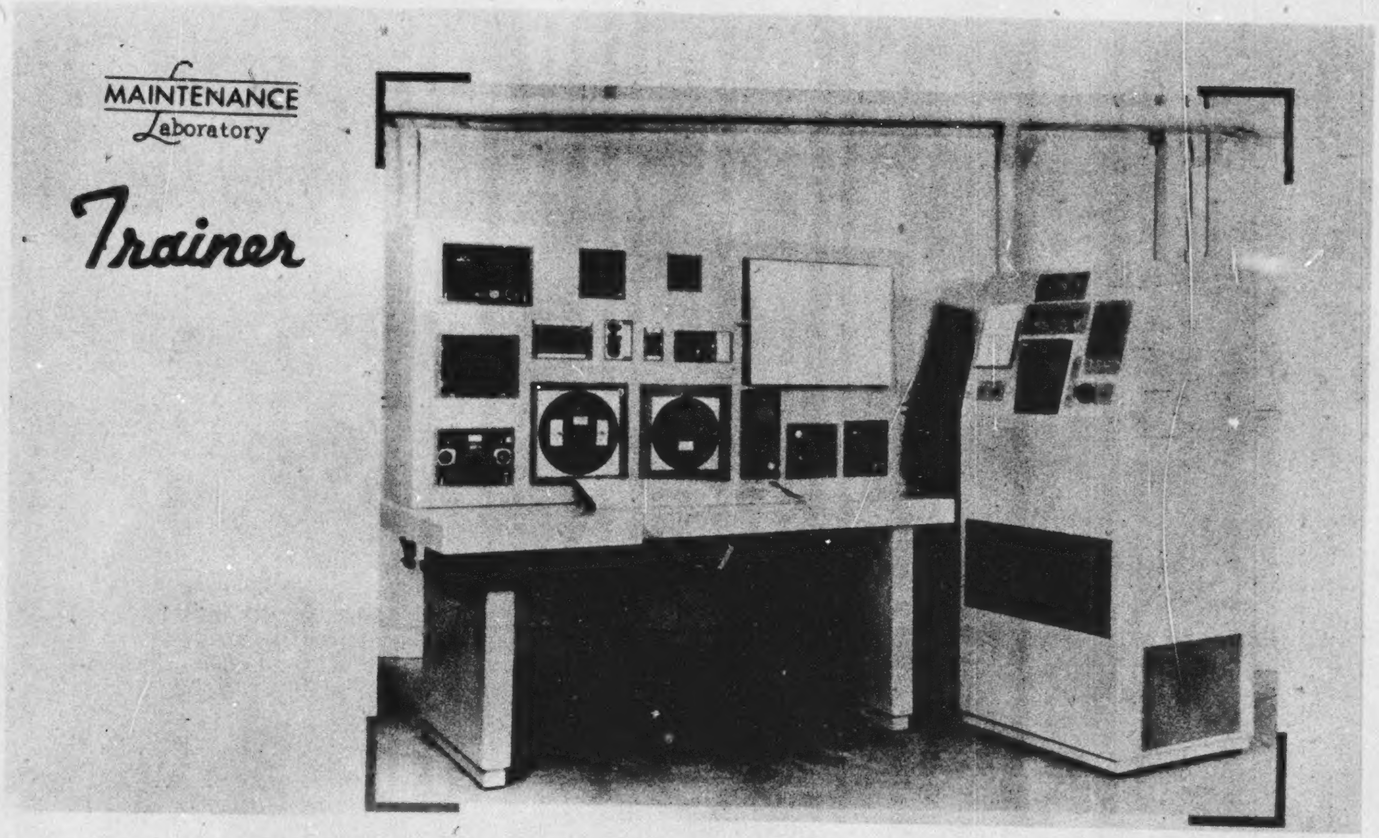

Figure 11-11. A Fire-Control System Troubleshooting Training Device. This combination of equipment has been studied experimentally in the training of fire-control technicians to provide concentrated practice in troubleshooting skills, coupled with correction and assessment of student performance. Essential system components simulated in the device at the left are used in conjunction with information presented by the microfilm projection device at the right. Sequence of information presented depends on responses made by the trainee. Beginning with a reported difficulty, the student can practice carrying the diagnosis of malfunctions down to the part level. Also included is a component for automatic recording of the student's performance.

with greater flexibility and superior logistic and economic qualities. The program-sequencer using microfilm or other information displays can, obviously, also be used with other systems, or reprogrammed rather easily by constructing new film materials, to take account of system changes. At the same time, revising or replacing the simulated components in the left-hand device for use with the new film program can up-date the total combination with much less time and expense than might be required to construct a whole new trainer or to make extensive circuit changes in a "MAC" type device.

Many further attempts have been made to reduce the operations and, particularly, the intellectual processes and decisions involved in troubleshooting of complex equipment and other diagnostic problems, to simpler symbolic materials or "paper and pencil trainers" (see also Chapter 12). Often, the crucial aspects of training are learning to make right decisions on the basis of information; and the question of the form in which the information is obtained, or the physical nature of the responses used to represent checks to obtain this information, may be relatively unimportant.

Troubleshooting Trainers in Relation to Job Aids: It is clear that some of the kinds of information required for the design of training procedures and training devices for complex tasks such as troubleshooting may also afford a basis for information sources which can be used not only in training but also on the job. This was noted, for example, for the malfunction information tabulation used with the "MIT" device depicted in Figure 11-5.

The availability of such devices as accessible on-the-job information sources may modify considerably the requirements for training that will be adequate to produce satisfactory troubleshooting capabilities in technical personnel. In particular, convenient accessibility of information that indicates the functional interrelationships of a system may mean that much less knowledge of system function and of underlying theory is required than would be needed without the availability of such job aids. Thus it is important to consider the potential availability of proceduralized troubleshooting guides (described in Chapter 7) in relation to the design of devices for troubleshooting training. Where suitable job aids can be made available for proceduralizing part or all of the troubleshooting on complex equipment, the specification of training requirements should take account of this fact, in two ways. The first way is that, as above indicated, the amount of conceptual knowledge which a training program must include can be considerably reduced (Berkshire, 1954; Hoehn and Lumsdaine, 1958). The second way is that the training program should provide explicit practice in the use of the proceduralized job information aids (in connection with manipulation of either actual equipment or synthetic practice devices).

The information in a job-training aid for troubleshooting may be presented in various formats and may make use of diagrammatic representations. The latter may either provide indications of contingent or "branching" sequences of procedure, in diagrammatic form, or may consist of data-flow diagrams with particular elements and pathways emphasized in such a way that effective checking procedures can be readily inferred. An example of such a "diagnostigram" (in this case, for troubleshooting a flight simulator) is shown in Figure 11-12 and is described in a report by Schweiker and Rulon (1958). Training to prepare a technician to utilize such devices in troubleshooting might well include practice in using them in conjunction with simulation devices such as the "MAC" trainer as well as in troubleshooting operational equipment.

Training in Motor Skills

Requirements: By "motor acts" the psychologist generally means nonverbal acts that comprise more or less complicated muscular adjustments of hands, fingers, legs, feet, or other parts of the body. These are generally guided by a changing pattern of "sensory feedback" which is provided as the act proceeds and which steers its successful execution. Such acts may be easy or difficult to learn, may be very short or quite extended in duration, and may differ in many other respects.

Many of these skilled motor acts consist of discrete units which are fairly short in duration and can be considered as independent units. The signal for completion of such a segmental act may be some form of identification or sensory discrimination not in itself requiring any motor skill. More complex motor acts are extended in time and include numerous component acts which must be integrated into a smoothly flowing sequence. These are encountered in many phases of human activity, such as playing a musical instrument, participating in a sport, or typewriting.

For the operation and maintenance of equipment systems, training in motor skills has in recent years become a problem of somewhat decreasing importance in relation to other kinds of training objectives. (This is, of course, largely a result of increases in automation of functions that formerly required complex motor coordination.) Thus, aside from the important problems of complex flight-system simulators (not treated in this chapter), the need for special training devices for motor skills has considerably less importance than it formerly had. For this reason, and because of the complexity of the problems encountered in the design of trainers for complex motor coordination (e.g., those widely used in formerly important tasks such as aerial flexible gunnery), such trainers are not treated in much detail here. Good accounts of some of the requirements for effective training of motor skills may be found in several publications by R. B. Miller (1953b, 1956a, 1956e).

Simpler Skills: Many of the simple and readily-learned motor skills required in carrying out procedures in adjustment of equipment systems require, despite their ease, considerable exactness and precision. Since much of the "feedback" in the performance of these skills is based on "feel," learning them is generally best accomplished by practice on operational equipment components that provide this kind of feedback in terms of resistance pressures, the felt location and textures of surfaces, etc. This practice may be considerably facilitated, however, if the relevant

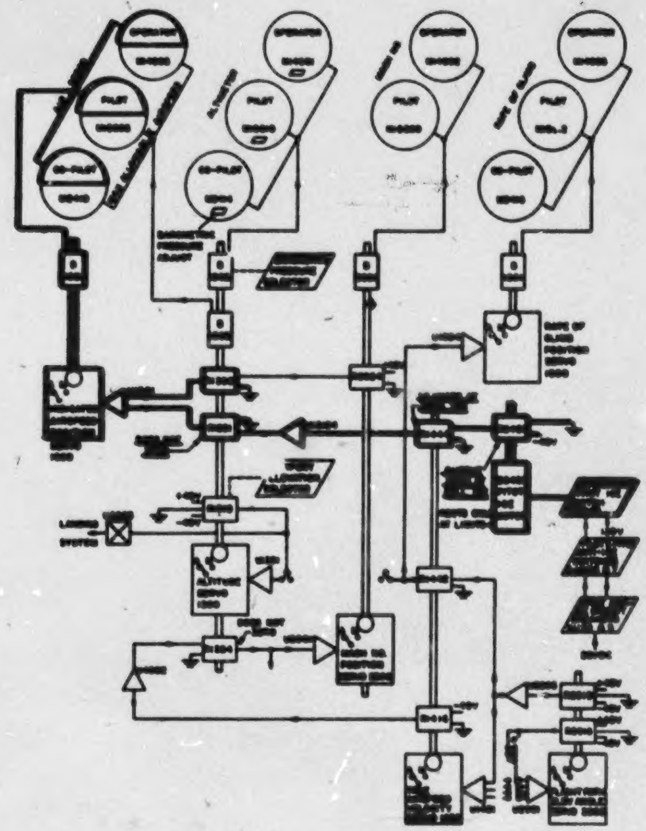

Figure 11-12. "Diagnostigram" for troubleshooting a flight-simulator. Such diagrams, representing essential elements, functional relationships and check-points of a complex system, have been designed to facilitate logical troubleshooting by simple "back-tracking" processes. This can be presented in a handbook as a job aid, or by slides or transparencies for class instruction.

information necessary to make the proper discriminations is first taught by efficient identification-training procedures. Final practice in the muscular adjustments themselves is generally best accomplished under the close supervision of an instructor.

In many instances, as in the case of procedural aspects of training, isolated equipment components can be used for this purpose with considerable gain in efficiency. For certain skilled acts, which must be performed in out-of-the-way locations that are difficult of access or impose similar difficulties, practice may be needed on the operational equipment as installed in the complete system, or mounted in a way that enables the mechanic to learn how to cope with difficult postural maneuvers or accomplish, by feel, an adjustment on a component which is not visible. (These requirements are sometimes not met in bench mock-ups of the equipment.) When special motor-skill training devices are used for this end, however, the requirements for their design are generally fairly obvious, once the foregoing considerations are recognized and borne in mind.

New Skills: With the development of advancing technology, certain new tasks requiring precise motor-skill coordination have come about. Adjustments to performing ordinary acts under "weightless" or other special gravitational or other unusual environmental conditions are a case in point but will not be dealt with explicitly in the present chapter. Another new class of tasks that has accompanied the development of nuclear energy is the use of remote manipulators for handling "hot" (radioactive) materials. These represent an important, although apparently not overly difficult, training problem. Practice in acquiring such skills can probably best be accomplished by the use of a device similar to the one shown in Figure 11-13, in which the "input" and "output" components of the manipulator are mounted close together, so that the trainee can readily observe the results of his actions and be given coaching by an instructor where required. Some additional problems may be encountered in training individuals to use manipulators in performing operations with materials which have to be remotely viewed by means of closed-circuit television linkages or similar means. The use of two-camera stereoscopic viewing devices for these purposes is a needed subject for research to determine the characteristics of training devices that incorporate remote-viewing components.

Skills Requiring Complex Simulation: As indicated at the outset, the design of complex simulators such as flight simulators is an advanced topic that is beyond the scope of the present chapter. The number of such complex devices that must be used in effective training can frequently be reduced by design of appropriate part-task trainers based on careful analysis of the components of job performance. Readers who are concerned with the design of more complex simulators may wish to consult reports by Miller (1953b), Gagné (1954), Williams and Adelson (1954), Swain (1954), Harter and Fitts (1956), Killian (1956), and Lybrand et al. (1958). An account of some complex simulation devices for team operations is given by Chapman and Kennedy (1956). Some pertinent considerations entering into the design

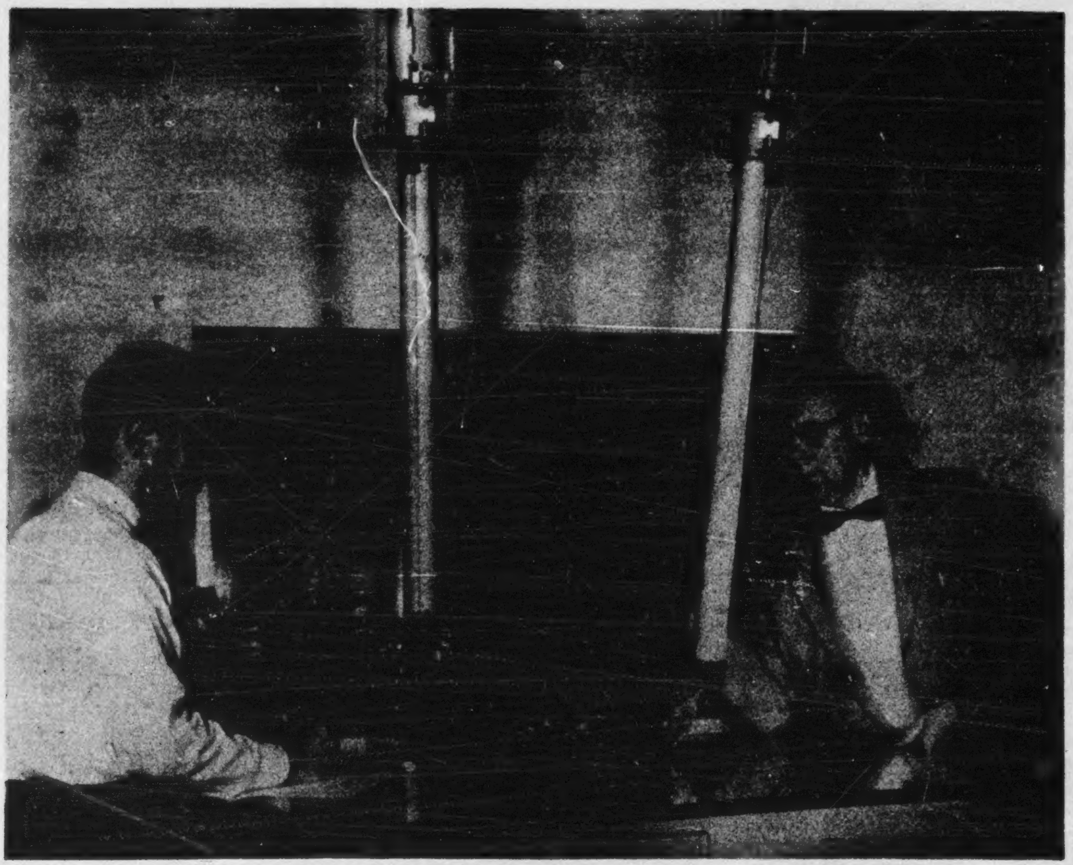

Figure 11-13. Remote-Manipulation Training Equipment. For tasks such as remote manipulation, where precise manual manipulation depends on "feel" coordinated with visual feedback, actual equipment may be preferable to artificial simulation. For training, however, equipment should be mounted so that it permits effective conditions of practice and coaching.

of simulators for training of team performance are indicated in conjunction with performance measurement in Chapter 13, and in reports by Glanzer, Glaser, and Klaus (1956), Glaser and Glanzer (1958).

Summary

1. Effective learning of the numerous identifications required in performing many tasks requires controlled, active practice by students, rather than mere class presentation by an instructor. Coach-and-pupil methods can be used to provide this, often using simple aids such as photographs or drawings in place of expensive equipment mock-ups. Practice should take account of the direction of association required in job activities. Knowledge of "facts" can often best be taught by similar practice on the basic one-to-one identifications to which they may be reduced.

2. An important and often overlooked **prerequisite** for effective and useful teaching of principles is to identify those principles which will actually need to be applied in performing job activities. These sometimes do not have much overlap with the principles that govern the physical functioning of an equipment system which a man is being trained to operate or maintain. Useful knowledge of the relevant principles requires practice in recognizing their application, and actively employing them, in diverse situations to which they apply. A program of exercises to provide this extensive verbal or symbolic manipulation often does not call for any complex training equipment, though controlled presentation and checking of such exercises to individual trainees may be greatly facilitated by appropriate self-instructional devices.

3. An exhaustive prior analysis and systematic tabulation of the multiple interrelations among malfunction conditions, mode of operation and output indications in a highly complex system can often be very useful as a basis for designing training exercises

and devices, as well as for codifying information in a form that can be used as a reference guide for job activities.

4. The effective teaching of exacting sequential procedures should proceed from a break-down of lengthy tasks into shorter ones, each of which can be learned by following step-by-step instructions or imitating a clearly presented demonstration. Suitably designed films are a good means for providing such demonstrations in reproductible, standardized form. These should be designed to allow immediate practice after each step of the demonstration.

5. The difficulty of recalling lengthy procedural sequences can be greatly reduced if training can be based on the availability of suitable job aids. Similarly, the requirements for troubleshooting training can be greatly simplified if proceduralized troubleshooting guides or similar job-information aids can be made available both in training and on the job.

6. Practice of many procedures by trainees can utilize incomplete components, surface mock-ups, or inexpensive replicas, reserving the use of functioning equipment primarily for those procedures which impose the need to respond to complex displays or to learn the "feel" of the response. Even for complex procedures, a combination of simulated and real components with special circuitry to provide feedback may provide a relatively inexpensive substitute for operational equipment. This applies both to procedural training and to practice in malfunction diagnosis. The design of such equipment can often be facilitated by substituting simple, "go/no-go" indicators to indicate equipment conditions. Use of inexpensive mock-ups wherever possible can improve training by making it economically feasible to provide sufficient intensive practice to assure "overlearning" of crucial operations and discriminations.

7. In particular, assuring sufficient practice in the interpretation of malfunction symptoms for complex systems and in choosing effective courses of action is likely to require synthetic devices, in which the effects of a wide range of malfunction conditions can be readily inserted for the student to diagnose. Simulated plug-in units and simplified indicators and controls can be employed in such equipment so that the results of diagnostic checks or hypothetical component replacements can be provided promptly to the student. Such devices, exemplified by the "MAC" trainer, provide efficient practice in basic decision-making skills, and form an important complement to practice with operational equipment.

8. As an alternative to trainers which simulate the data flow of a particular equipment system by functional interconnection of components, devices that present programmed exercises in symbolic form have the advantage of greater flexibility in adapting to system changes. Such readily reprogrammed problem-and-information presenting devices can be coupled with the use of relatively simple mock-ups of the external configuration for a particular system by use of coded inputs. This combination offers possibilities for system simulation of troubleshooting problems that can be adapted to system changes merely by constructing new program materials and making superficial changes in surface configurations, rather than by complete redesign of complex training-equipment hardware.

9. The sometimes very complex requirements for effective motor skills trainers are not treated in detail here, in view of the decreasing prevalence of motor-skill requirements in many jobs. Skills requiring precise muscular adjustment to feedback from the "feel" of the operation are often best taught by suitably guided practice on the operational equipment or on a complex simulator.

Classroom Training Aids

Use of "Classroom Trainers" that Depict Equipment Characteristics

Currently, there is the beginning of a desirable trend for designing training devices that are specialized for effectively attaining particular kinds of training objectives, as described above. This tendency is still only an incipient and partial one, and a great many classroom training devices are still constructed which must somehow be used for trying to attain several kinds of training objectives that the designer has not always had clearly in mind at the outset. These training aids are characteristically organized in terms of equipment systems rather than in terms of training functions.

These "classroom trainers" are used, in practice, primarily as visual aids for classroom lecture-demonstrations. Some of them are mock-ups consisting of actual equipment components. The latter are sometimes mounted in such a way that system functioning can be demonstrated. The "demonstration" thus provided should be sharply distinguished from the kind of procedural demonstration used as a basis for giving directions which the student will imitate in acquiring procedural skills, as described in the section on "Effective Use of Procedural Films" above.

The "demonstration" usually afforded in classroom use of devices is usually not a demonstration of procedures but a "demonstration" of system functioning. This is given on the rationale that understanding or observing the operation of the system will lead to understanding about its functioning that may be useful in its operation and maintenance at a later time. As already noted, this assumption is often questionable, and may fail to be supported by an analysis of what men actually need to do on the job.

There are also two weaknesses in the way such demonstrators are customarily used. First, so much time frequently elapses between the instructional demonstration and any application of what has been presented that much of what has been learned is forgotten by the time it could be applied. The second weakness is in the inherent characteristic of the lecture-demonstration form of instruction, which provides no means for assuring that sufficient recitation and repetition is provided to guarantee that the student gains any real mastery of the material. These deficiencies have been clearly demonstrated in experiments in which objective tests were used to reveal the amount of information retained immediately after the lecture-demonstration as well as the amount, if any, retained by the time the information was presumably to be applied--a number of days or weeks later. Some data illustrating these points, and also indicating something about the comparative effectiveness of the various forms of lecture aids, are presented in reports by Swanson (1954), Swanson, Lumsdaine, and Aukes (1956), and Shettel, et al. (1956).

Classroom training devices are commonly classified into several broad categories on the basis of salient features of their physical characteristics. This basis for classification is often a reflection of the fact that training objectives have not been defined in terms of the human performances that need to be achieved, so that the various forms of devices merely reflect different forms of system depiction rather than being conceived in relation to specific functions of training. The major categories of equipment are:

1. "Operating mock-ups," using actual equipment components interconnected so as to function more or less in the way they do when installed in operational locations.

2. Nonoperating mock-ups, similarly arranged and consisting either of equipment components or replicas designed to simulate closely the appearance of the actual components.

3. Cutaway mock-ups, generally composed of actual components that are partially dissected to afford a display that reveals internal appearance and sometimes shows internal functioning.

4. So-called "animated panel" displays, in which the system components are depicted pictorially and/or by simple semi-functioning models constructed of plastic, plywood, etc.

5. Transparancies and related devices such as slides, using optical projection of a transparent photographic representation.

6. Wall charts for classroom display, using photographic or other pictoralized representations of system components, their connections and operation.

In addition to these six classes of visual aids, an important classroom teaching device is the self-contained film presentation, including sound filmstrips and sound (or sometimes silent) motion pictures, which are further discussed under "Special Forms of Classroom Aids," below. Important features of these, aside from the obvious capability of depicting motion, are that (1) they are automatically sequenced or programmed, and (2) they are self-contained, in the sense that they provide a total presentation of depiction and exposition. The latter characteristic distinguishes them from the first six classes of classroom devices, which are normally used only as visual aids to a lecture by an instructor whose individual skill, in organizing and presenting the lecture, often determines the usefulness of the visual aids to a much larger degree than the inherent characteristics of the devices themselves.

Specific Characteristics of Six Forms of Visual Aids

Certain characteristics more or less specific to each of the six above-noted kinds of visual aids are worth considering, especially in view of the wide use of such devices and the prevalance of the method of classroom instruction for which they are employed. Their uses for this purpose as well as some potential other uses are discussed below.

Operating Equipment Mock-Ups: A representative panel mock-up of this type was shown in Figure 11-1, for the hydraulic system of the B-47 medium bomber. A different type of mock-up is shown in Figure 11-14. An alleged advantage claimed for such devices is that they show actual system function. This characteristic is frequently not employed in actual classroom instruction for more than a brief period. Often, because of the difficulty of maintaining the device it is not employed at all, and in some instances the noise produced by operation of the equipment is so great as to prevent its operation from showing much of anything except that the system does, sure enough "work"--a conclusion which the student might reasonably be asked to take on faith. In addition, the cost of such devices is very great. Accordingly, it is difficult to recommend the large sums that they commonly require, particularly in view of the fact that the functions of visual display for which they are in fact primarily used can be served as well or better by much less expensive forms of classroom training equipment.

The exception of this rather strong indictment of such devices lies, of course, in those cases where students can usefully perform actual practice work with them, such as troubleshooting an operating system. This might, for example, be accomplished to some degree with such mock-ups of electronic equipment as the one depicted in Figure 11-14. However, the complex operating mock-up is commonly not made available for required practice and its potentialities are thereby lost.

The nonavailability of such devices for student practice in working on them stems from two considerations: First, such devices are often very expensive, and thus are not available in sufficient numbers to permit any useful amount of individual student practice in assembling, disassembling, adjusting and regulating them. Second, because of the costliness of the devices and their demand for instructional classroom demonstration (in view of the unavailability of other kinds of aids suitable for this purpose), the student is not permitted to "tamper" with the equipment.

There are two consequences to this unfortunate situation. One is that the main justification for operating mock-up devices exists only in theory rather than in practice. The second is that the first actual practice the student gets is on the operational equipment--often not until he is assigned job responsibilities in an operational situation. This of course may have consequences that are vastly more costly than it would be to provide component mock-ups on an adequate basis of issue for the purpose for which they are best suited, namely for the conduct of practice on procedures and malfunction diagnosis.

Nonoperating Mock-Ups of Actual or Simulated Three-Dimensional Components: Devices like the one shown in Figure 11-1 are frequently used as visual aids for lecture presentations, in nonoperating condition though with intact elements of operational equipment functionally interconnected. An alternative which has been explored is the use of simulated components, depicting the actual ones with a high degree of fidelity, but consisting

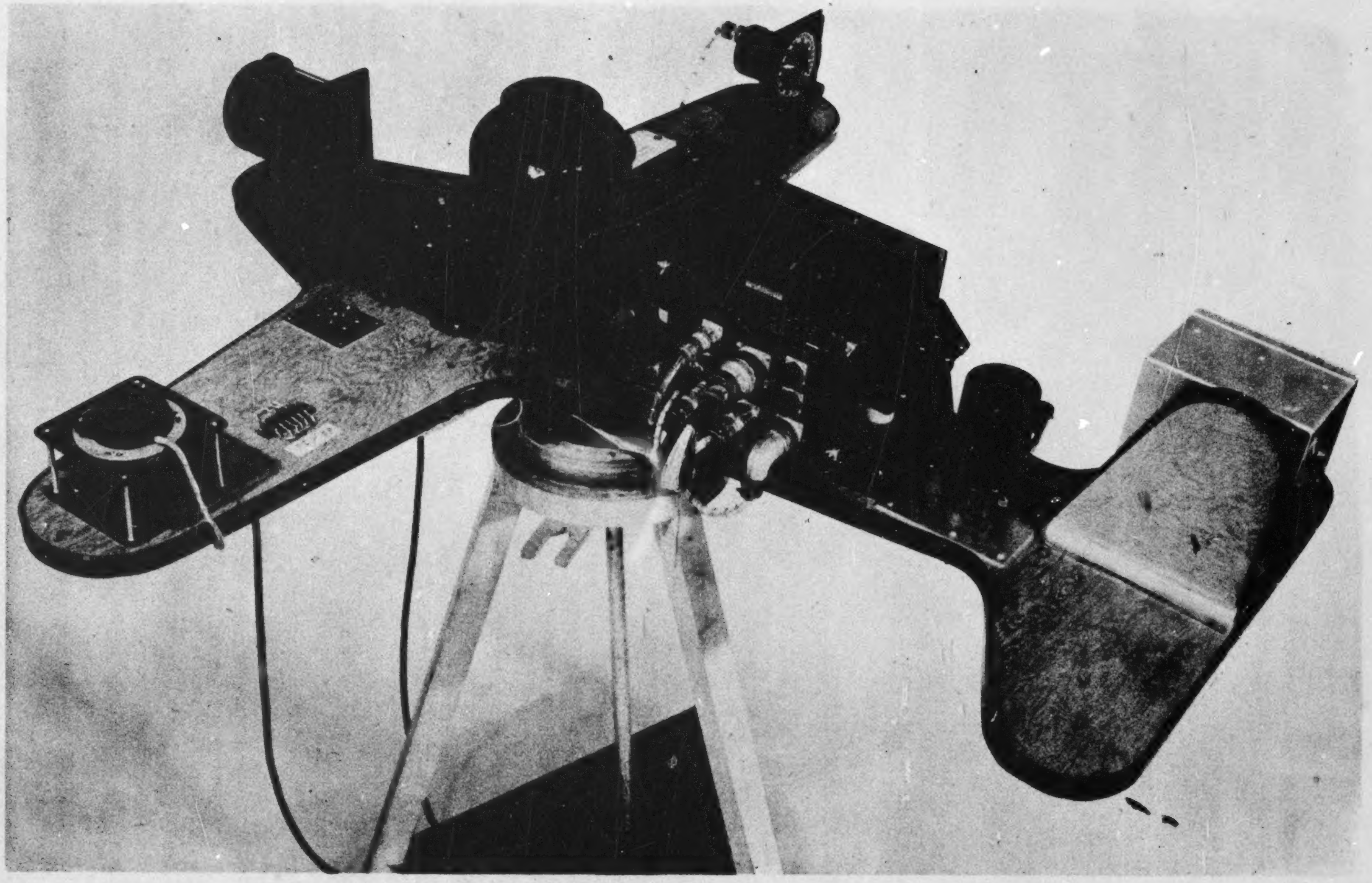

Figure 11-14. A "Working Model" Trainer which Simulates the Effects of Operation of an Aircraft Subsystem (Autopilot). Such devices may be of doubtful value unless designed to provide simulation of task conditions for effective practice of job elements, rather than merely demonstrating the physical functioning of the system.

of plastic and other ersatz materials. To the extent that an exact, three-dimensional replica of equipment components is desirable, the latter can have the advantage of being lighter and possibly cheaper, especially if a large number of copies is required. In addition, they may help solve the problems of lead time, and avoid the competition for actual components between the needs of training and those of meeting demands for operational use of equipment.

However, the advantage of the three-dimensional replica may be seriously questioned as classroom aids as compared to less expensive depiction by means of realistic charts, photographs, transparencies and the like. Simulated components made of plastic may also fail to provide the necessary characteristics for adequate practice of some of the skills involved in removal, positioning, assembly, disassembly, and the like. Accordingly, the designer of training equipment should very carefully analyze the function that any expensive synthetic components are designed to serve before recommending that they be developed and manufactured.

Cutaway Mock-Ups Employing Actual Components: These devices are often arranged much like the configuration in Figure 11-1. With rare exceptions, the advantages of such devices over well-designed photographs or drawings (see Figure 11-3), supplemented by occasional disassembly of components for practice in performing internal adjustments, can be seriously questioned. This is particularly true in view of the usually very high cost of the cut-away assembly.

One purpose which a single copy of a cut-away or other nonoperating mock-up may usefully serve, in some instances, is that of affording a convenient way to assemble the equipment for use in producing photographs, charts, transparencies, and other two-dimensional visual aids. For this purpose, of course, it may frequently be advantageous to use a quite different layout and form of construction for the single copy of the mock-up than what would be required for constructing mobile display panels. For example, the parts may be laid out more realistically in relation to the locations where they would normally be found in operational situations, they need not necessarily be so ruggedly mounted, etc.

"Animated Panel" Displays: Two examples of these are shown in Figures 11-15 and 11-16. The first, in Figure 11-15, is a display for the hydraulic system of the B-47, and was used by Swanson (1954) in the above-cited experimental comparison of learning from lecture-demonstrations on B-47 subsystems. It actually consists mainly of an enlarged diagrammatic representation of the system, using simplified representations of components with painted lines to represent tubing interconnections. Some of the components are constructed with moving parts to illustrate their operation.

The device shown in Figure 11-16 is one of a number of types of "illuminated animated panels." Such panels may employ indicator lights, transparent drawings which may be illuminated (sometimes in multiple modes

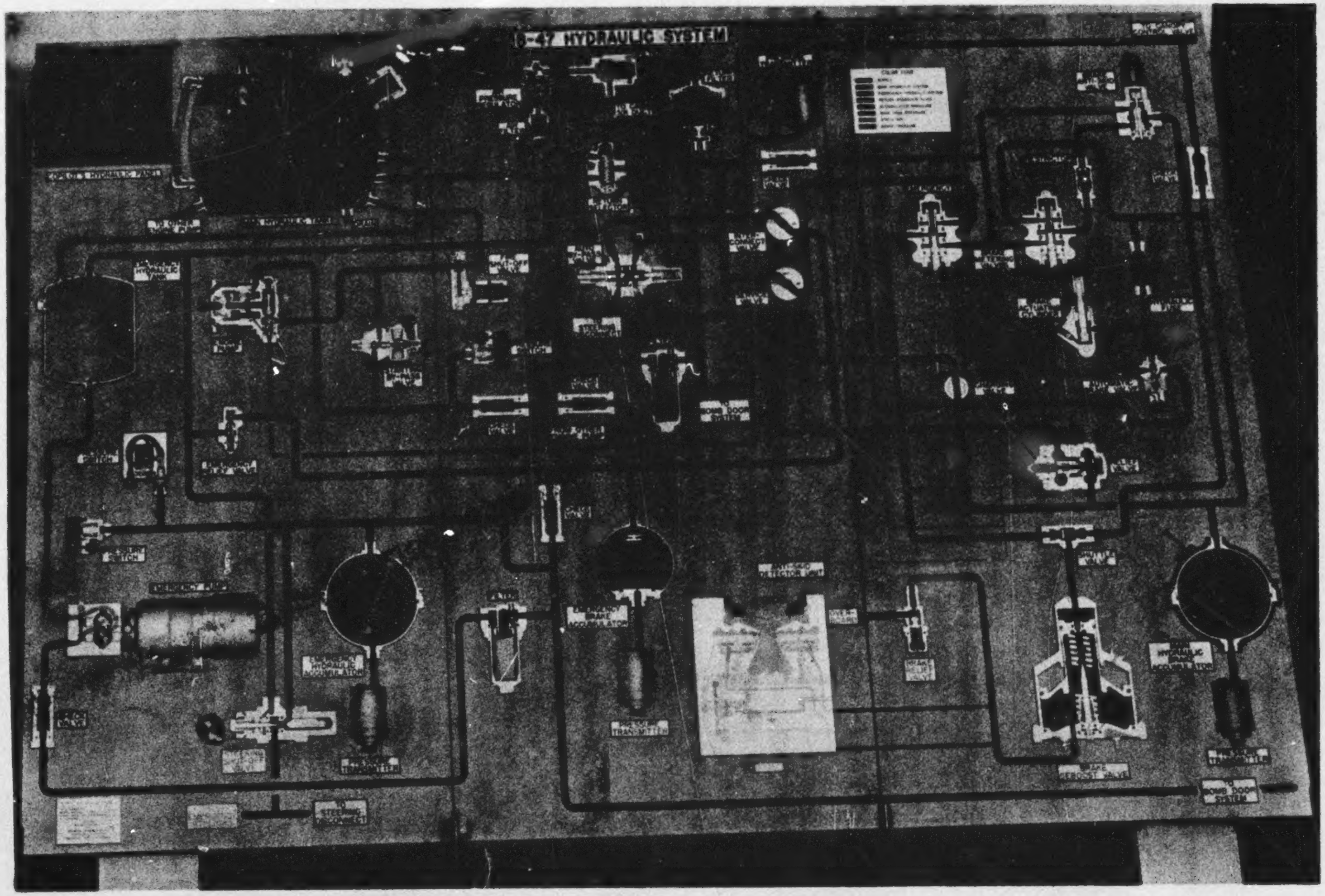
B-47 HYDRAULIC SYSTEM

Figure 11-15. So-called "Animated Panel" using Simulated Components (some with moving parts)

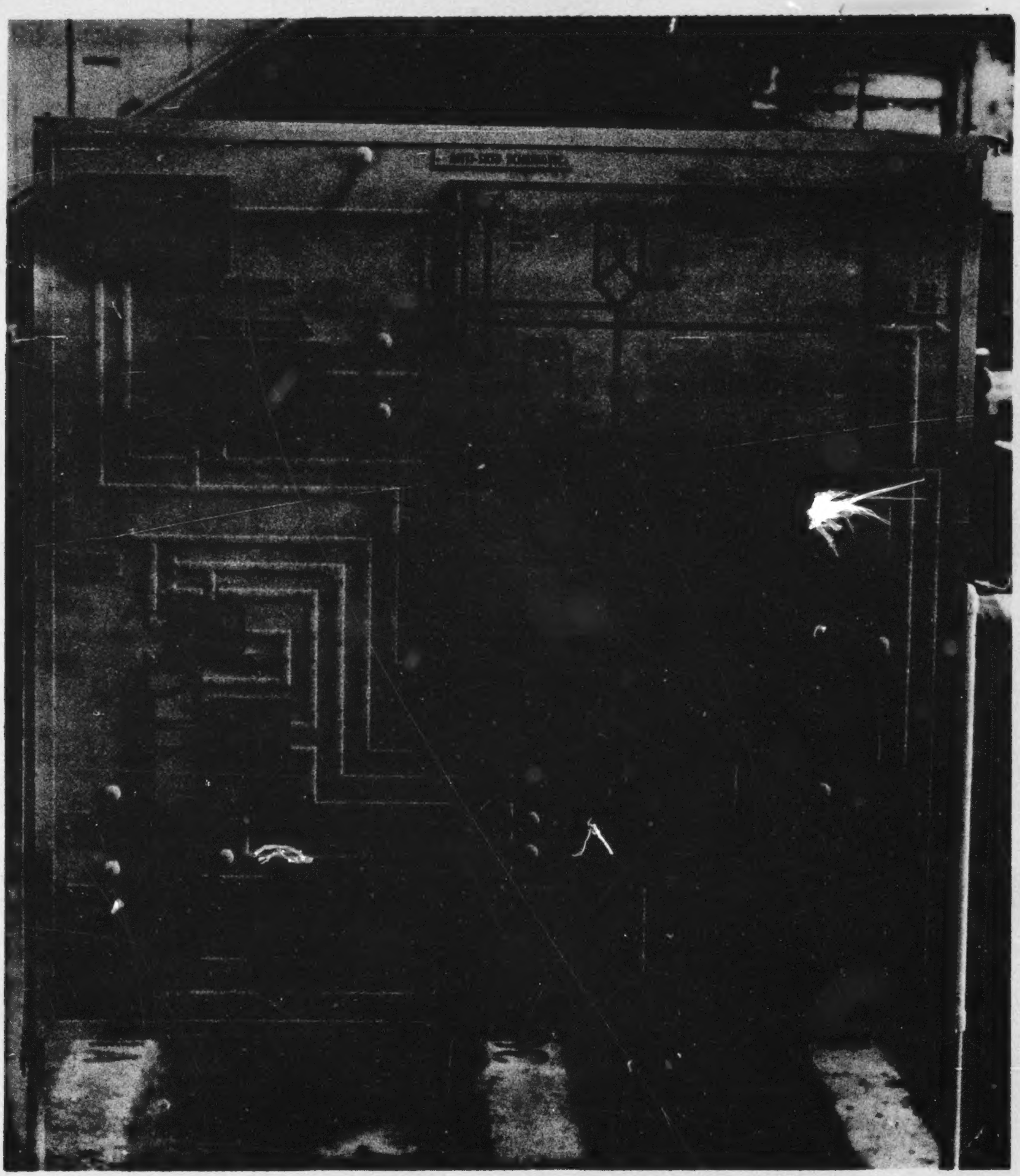

Figure 11-16. Illuminated "Animated Panel" for an Electrical System. Various schemes of illumination of pathways and components are used to indicate system functioning in a lecture-demonstration. Value of such aids can be questioned as compared with various alternative devices (see text).

to show different aspects of operation or produce apparent motion of internal components), and various forms of illuminated pathways showing electrical, pneumatic, or hydraulic interconnections between such components. In many such devices, the pathways involved in different phases or modes of operation can be differentially illuminated to increase clarity of depiction.

This kind of differentially illuminated display can undoubtedly have some advantages in depicting the principles of system functioning and, where these are the principles actually needed to be applied in the performance of a technician's job, the animated panel might serve a useful training function. However, an equivalent display can very often be created and reproduced at very much lower cost by the use of transparencies (see Stolurow and Lumsdaine, 1956).

Transparencies: As with slides, these are used with a standard, general-purpose transparency projector. It projects a series of transparencies providing much the same kind of visual display as the animated panel. Considerable flexibility and variation of depiction in such transparencies can be accomplished by the use of multiple overlays and other devices for providing differential illumination of components or pathways. As compared with the animated panel, the transparencies are, of course, far lighter and more convenient to use, as well as much cheaper and faster to produce.

In view of the many advantages of transparencies, the cost and time involved in the design and construction of animated panels can be very seriously questioned. A detailed consideration of illumination and depiction characteristics of such displays is provided in a report by Stolurow and Lumsdaine (1956). A more detailed consideration of some of the pertinent aspects of visual displays applying both to the illuminated and other forms of graphic training aids is provided in a report by Saul et al. (1956).

Wall Charts: One of the disadvantages of a total equipment display, such as those shown in Figures 11-1, 11-15 and 11-16 is that so much material is present that a student may be distracted from focusing his attention most effectively on a particular aspect. A study by Aukes and Simon (1957) for example, showed that somewhat better learning was obtained in a lecture-demonstration with an "add-a-part" display in which various subassemblies were added to the display as they became relevant to the accompanying exposition presented by the instructor. This kind of advantage can be readily realized by use of charts such as those shown in Figure 11-17. Such a display shares with projected transparencies the further advantage that different forms of depiction can be used as appropriate.

Within the basic limitation of training functions which can be served by the lecture-demonstration procedure, the flexible use of such devices, in the form of transparencies or wall charts, has an outstanding advantage over other forms of displays, and should be given very serious attention in competition with other more expensive and cumbersome teaching aids. Because

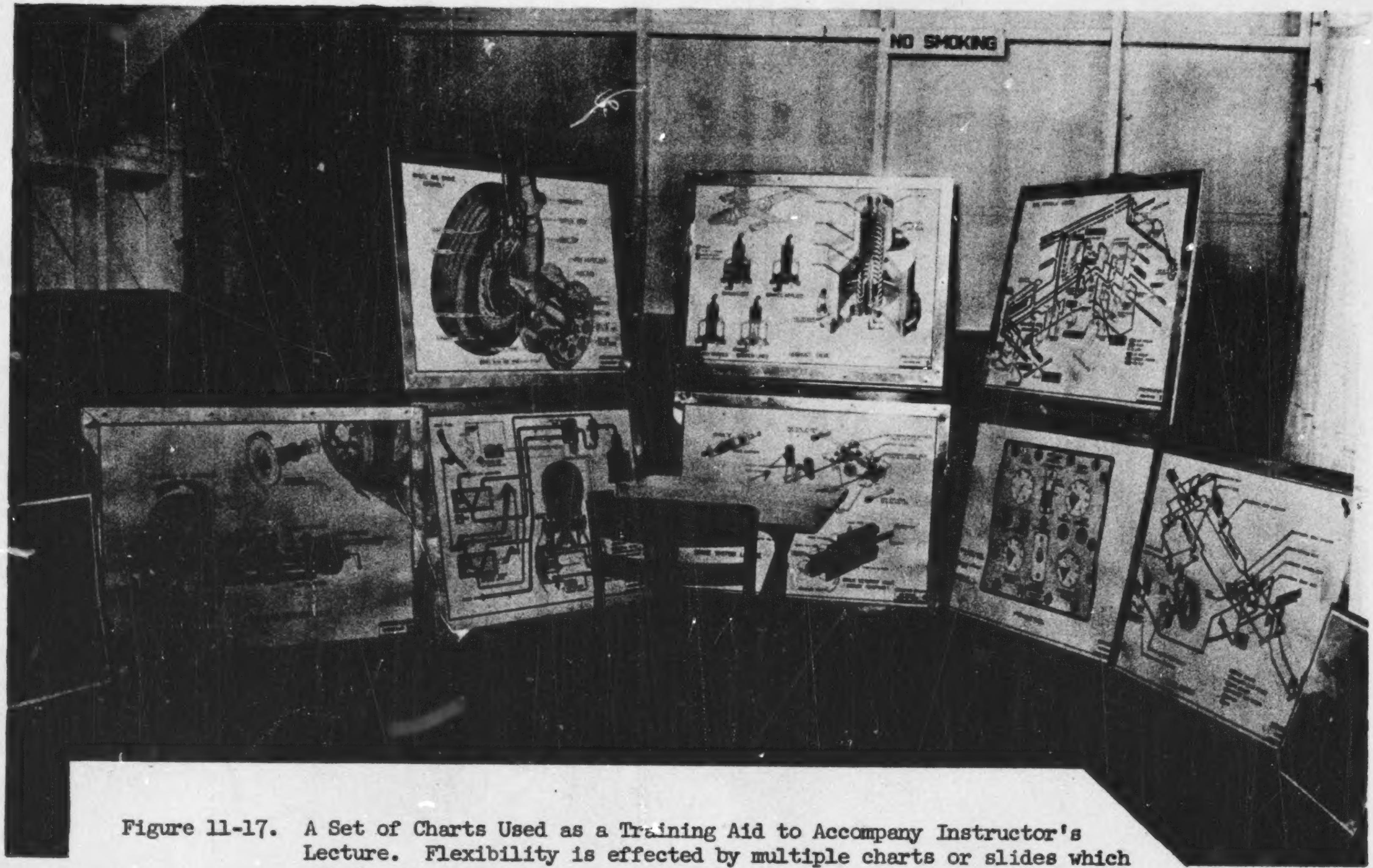

Figure 11-17. A Set of Charts Used as a Training Aid to Accompany Instructor's Lecture. Flexibility is effected by multiple charts or slides which are designed to depict a particular aspect of equipment construction or function.

of their much greater flexibility and often superior convenience and durability, transparencies are very often preferable to wall charts, except where such factors as poor room ventilation give the wall charts an advantage.

The cost of supplying an ample number of projectors for transparencies or other projected aids is negligible as compared with the cumulative cost of providing new equipment mock-ups for each new system. Adaptation to new requirements can be accomplished simply be constructing new materials--transparencies, films, for a new system. The cost per system for projectors is very low indeed, because their longer useful life means lower net cost per student, amortized over a period of time. Consequently, a larger number of devices can be economically procured. We might, for example, buy enough film projectors and sets of transparencies to have one for every five students, for the same amount that it might cost to buy one operating system mock-up per system for every fifty students. This difference in equipment availability can be a crucial factor in the effectiveness of training--for example, by making it possible to schedule instruction for each student just prior to the time when he will put the information to practical use.

Special Forms of Classroom Aids

Motion Pictures: Special applications of motion pictures for procedural training have been noted above. In some cases their use for special applications of this kind may be more important than their use for ordinary classroom instruction. Nevertheless, when classroom instruction of the lecture-demonstration form is to be used, well-designed motion pictures have the advantage that they represent a self-contained or almost fully "automated" form of presentation. Because of this fact, they can escape from the limitations imposed by the shortages and deficiencies of local instructors, which in practice often seriously limit the effectiveness of visual classroom displays. This is particularly important since, as shown by research studies, a large amount of the information that is imparted in classroom lecture-demonstrations may be conveyed primarily by the spoken material rather than by the visual display (see Swanson, Lumsdaine and Aukes, 1956).

The cost and time required to produce films aimed at very specific instructional objectives is often surprisingly low as compared with general-purpose familiarization films or other "training" films of the kind that employ elaborate dramatic sceneries patterned after the entertainment film industry. Satisfactory films can often be produced locally with very limited equipment--see the previously cited report by Greenhill (1955). Major references that provide guidelines and research evidence on the effectiveness of instructional films are those by Hoban and van Ormer (1950), N. E. Miller et al. (1957), and May and Lumsdaine (1958).

One kind of film can be produced very inexpensively indeed, by simply taking a "TV-style" filmed record of a good lecture-demonstration that employs appropriate visual aids. This technique has been used experimentally in the Air Force (see Shettel, et al., 1956). Use of two cameras permits flexible utilization of close ups and shifting from one display to another. Such a film can be quickly filmed, and easily refilmed to update it. Like other films, it can be reproduced and transported cheaply, can utilize more proficient instructors than are normally available in the field, and--perhaps most important--can be shown or repeated shortly before the information it presents needs to be utilized on the job (Shettel et al., 1956).

Since most of the material taught by any form of lecture-demonstration is often quickly forgotten, particularly if not soon put to active use, this feature can make the filmed presentation considerably more effective than an equivalent "live" presentation. It may be noted that this kind of filmed lecture-demonstration has recently acquired a considerably vogue in public education, as illustrated in the year-long filmed courses in physics and chemistry sponsored by the Ford Foundation and distributed by Encyclopaedia Britannica Films.

"Mixed" Types of Classroom Demonstration Devices: Devices combining a full operational mock-up together with test instruments and integrated supplementary display panels may be used for classroom demonstration purposes as well as sometimes being adaptable for individual practice in performing certain job operations. One example is the combination of training devices for the F86D electronic fuel control system that is shown in Figure 11-18.

A somewhat different kind of combination is represented by the jet-engine training device shown in Figure 11-19. This combines actual aircraft instruments, and some controls, with an illuminated panel. It is designed to show internal engine operation correlated with control actions and corresponding instrument indications. Provision is included for demonstrating how both internal functioning, and outward indications of instruments in response to control settings, are affected by certain malfunction conditions. Where an understanding of the internal working relationships contributes to the ability to apply principles in proper interpretations of observable indications from instruments and other symptoms in malfunction diagnosis, such a device may have considerable training value.

However, much will depend on a careful analysis of the way in which the information displayed does actually contribute to job operations and of the extent to which the use of the device results in these interrelations actually being learned and applied by the student (see West, Smith and Stolurow, 1957, and Adams et al., 1957).

In cases where it is decided that the kinds of displays afforded by such a device may make a useful contribution to training, consideration should be given to the possibility of representing them through more flexible and inexpensively reproduced means such as a combination of transparencies and short motion picture "film clips." In some instances, production of the latter might be facilitated by basing them in part on filmed demonstrations of a single prototype equipment mock-up somewhat similar to the one shown in Figure 11-19.

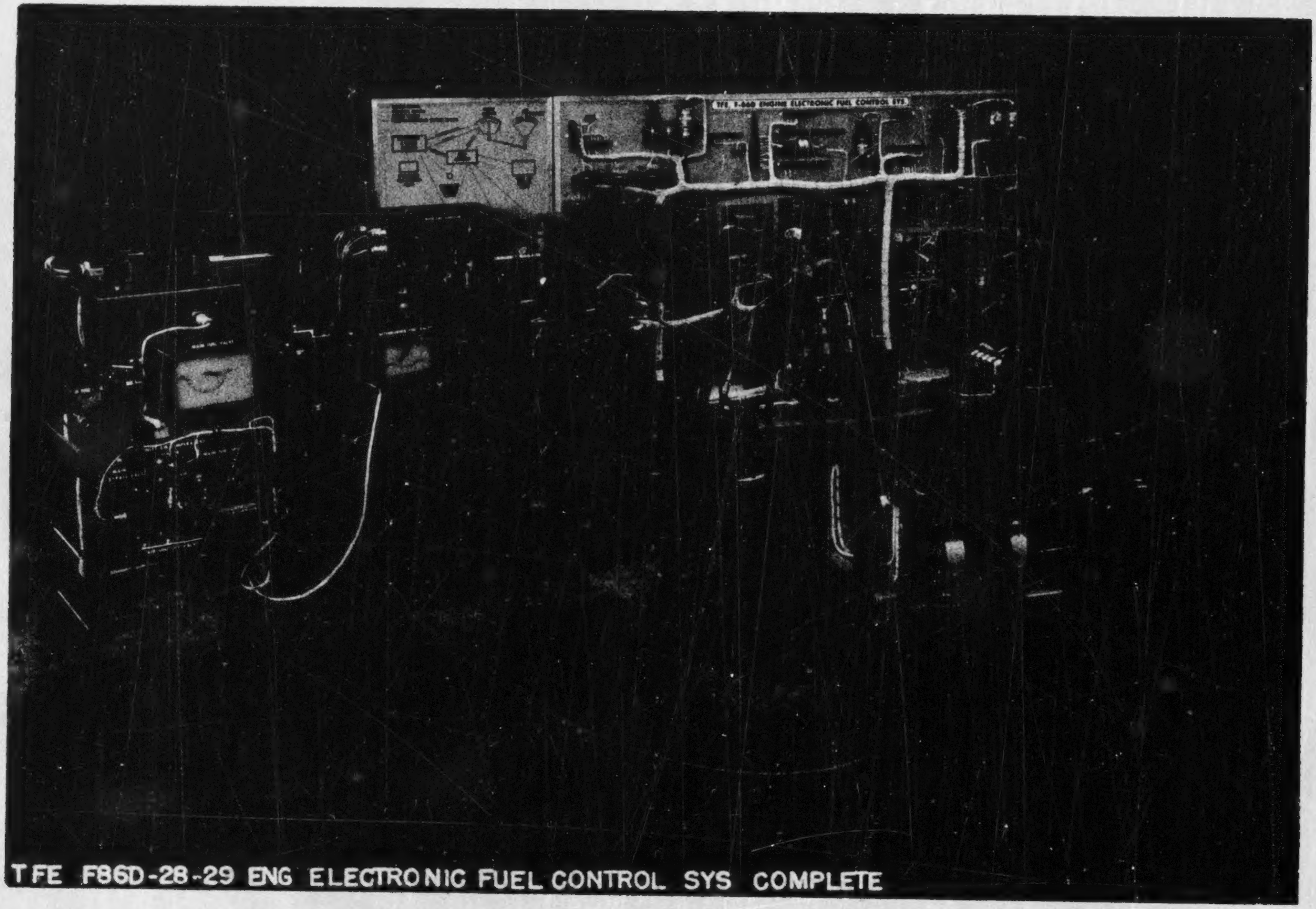
TFE F86D-28-29 ENG ELECTRONIC FUEL CONTROL SYS COMPLETE
TFE [illegible] ENGINE ELECTRONIC FUEL CONTROL SYS

Figure 11-18. System Mock-Up with Associated Test Equipment Required for System Check-out. This is coupled with complex panel displays to permit depiction of system operation and some practice in tracing malfunctions.

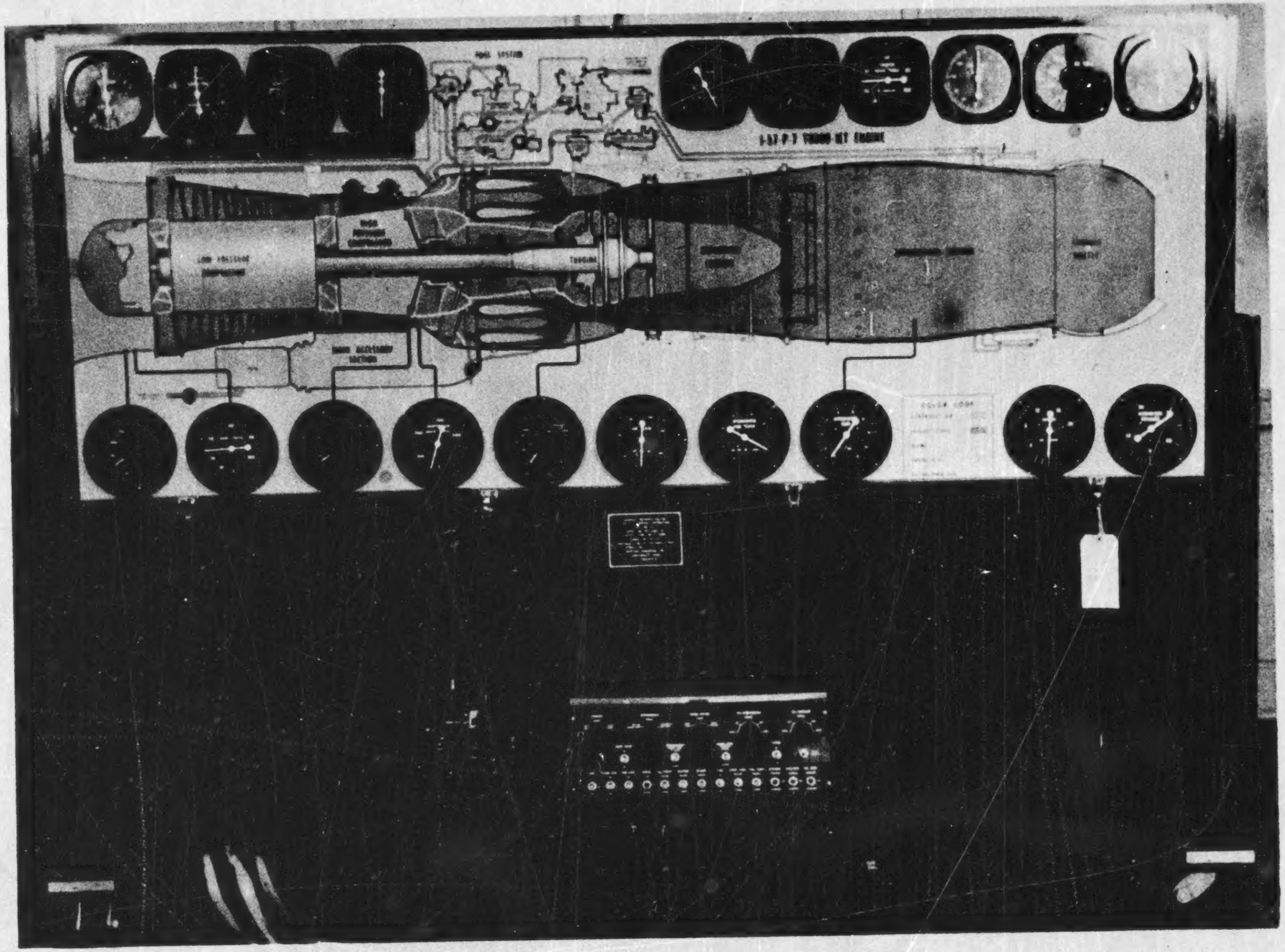

Figure 11-19. A Complex Training Device for Depicting Certain Aspects of Jet Engine Operation and Instrument Displays that Correspond to Various Operating Controls. Some, but by no means all, malfunction conditions can be represented by the instructor's control box.

Summary

1. The effectiveness of devices used as visual aids for presenting information about equipment components and functioning depends to a large extent on the ability of the instructor to contribute to attainment of training objectives through the often quite inefficient method of lecture-demonstration.

2. Within its inherent limitations, such instruction will be most effective if given shortly before the student is to make active use of the information presented. This and other factors militate in favor of using inexpensive, two-dimensional displays reproduced in multiple copies.

3. The use of expensive operating or nonoperating equipment mock-ups using actual or simulated components as lecture aids is frequently very questionable as compared with simpler, less expensive and more convenient kinds of aids. In general, mock-ups should be reserved for actual practice of procedures by students. A single mock-up may also be useful as a basis for constructing photographic transparencies, films or other two-dimensional aids.

4. The variable display afforded by animated panels of various sorts can sometimes provide a superior display for explaining system functioning but, in view of the expense of the complex illuminating panel, the use of comparable displays presented by multiple-overlay transparencies is generally to be recommended as preferable.

5. Projection equipment for effective use of transparencies and films can be available in each classroom for comparatively little cost as compared with that of equipment mock-ups. Materials for use with such devices can be prepared relatively cheaply and quickly, permitting ready

adaptation to system changes, if available short-cut production methods are used.

6. Motion picture presentation of information has the advantage over lectures that it is self-contained, standardizable at high quality and, unlike usual forms of classroom visual aids, does not depend predominately on the local availability of expert instructors.

Some Special Factors in Design and Use of Training Devices

Active Student Response in Classroom Instruction

Some of the major disadvantages of classroom lecture-demonstration instruction can be partly offset, with resultant gains in training effectiveness, if provision is made for active student response during the presentation of the class instruction. The latter should be designed to serve much the same functions of quizzing, active rehearsal, checking, and correction as in the case of the teaching machines and other individual-practice devices discussed in Chapter 12. Where individual instruction of this kind is not possible, these functions can sometimes be effectively implemented in classroom instruction by the use of appropriate training devices, even though the advantages of permitting individual students to proceed at a rate commensurate with their individual abilities is necessarily lacking.

Convincing evidence of the value of this technique is found in a number of studies in which the contribution of "active participation" or active student recitation, interspersed between segments of presentation by an instructor or a film, has been shown to result in marked gains in the amount learned. Following an initial study conducted during World War II, in which this technique was used with a film for teaching simple verbal associations (see Hovland, Lumsdaine and Sheffield, 1949). the technique has been adapted and extended to the learning of conceptual materials and various kinds of skills. Reviews of some of these studies are presented by Allen (1957) and Lumsdaine (1959a). They are well worth consulting by the individuals who wish to improve the effectiveness of class instruction. The evidence indicates that such devices can contribute appreciably to student motivation in a classroom situation, relieving boredom and inattention, but that their primary contribution is in terms of the direct effects of the practice that is provided on the learning of specific materials.

Successful application of this technique usually demands three things:

1. Careful analysis of the objectives of training to determine the principles, associations, and skills that are most difficult and crucial to learn.

2. Advance planning of the classroom instruction procedures to make provision for an appropriate amount and type of group practice, "recitation" or similar "participation."

3. Provision of appropriate devices and materials which students can use effectively in such classroom exercises.

These materials may consist of simple answer sheets in which answers are recorded in verbal or numerical terms. In other cases it may be desirable to use worksheets such as the one shown in Figure 11-20, on which responses to questions and short problems posed by the instructor are indicated on schematic or functional diagrams that correspond to the display presented by the instructor (cf. Figure 11-19). Actual or simulated equipment components (cf. Figure 11-4) are also useful to allow student response to exercises or questions posed by the instructor or by a specially-designed film.

The most effective use of the active class-response technique can perhaps be made by building provision for the recitation-practice activities into a basic training device from the outset. This is clearly illustrated in the case of films, where appropriate questions to be answered at numerous preplanned stopping points in the film can be posed verbally and pictorially in the film itself.

Another way of implementing this technique can be used where the subject matter is of a nature that verbal or symbolic responses can be readily coded in simple multiple-choice fashion. This is through the use of a device such as that shown in Figure 11-21. This is one of a family of classroom response devices in which each student indicates his answer, to questions posed following short segments of instruction, by indicating an answer choice with a switch that can be connected to a central console. The latter provides the instructor with a visual indication of the proportion of students responding correctly and, if desired, the proportion giving each wrong answer choice.

Similar devices have been described by Carpenter, et al. (1950). A simple and fairly satisfactory device can often be constructed out of available components. More elaborate devices can permit totaling the errors for individual students to give each one a cumulative "score," and thus provide a continuous testing function during the course of instruction. Beneficial effects on student motivation and attention that can result may or may not justify the added cost and complexity that is involved. In general, simpler devices have much to recommend them for most purposes. As in the case of the individual self-instructional devices discussed in Chapter 12, the most important factor in the effectiveness of using any such devices for active student response lies in the programming of the instructional exercises which are used in conjunction with it.

A special advantage of even a simple device of this type in a flexible presentation provided by a good classroom instructor is that the instructor can modify his presentation on the basis of the feedback. He can thus clarify points which an appreciable proportion of the class appear to have missed.

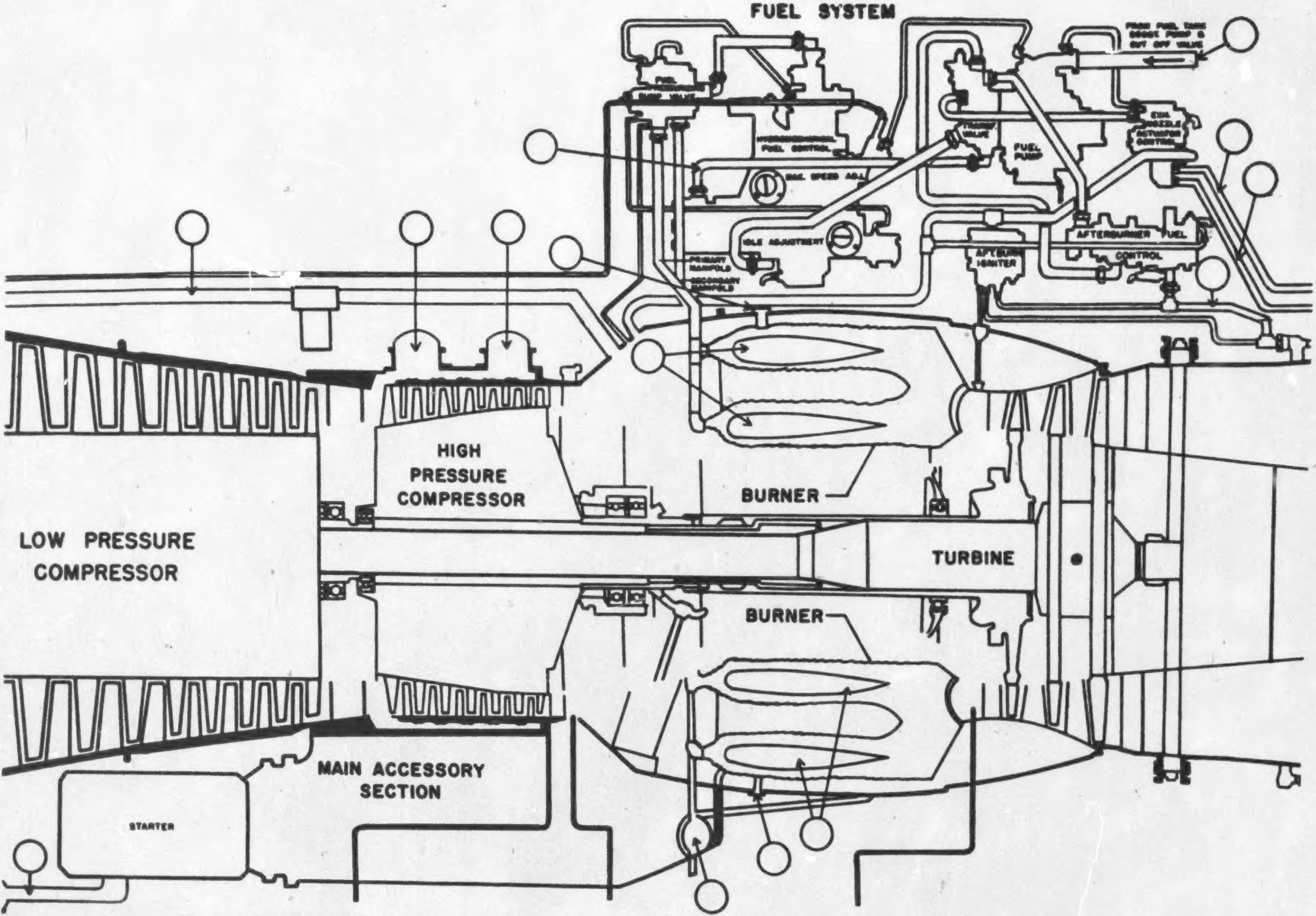
FUEL SYSTEM
FROM FUEL TANK BOOST PUMP & CUT OFF VALVE
HYDROMECHANICAL FUEL CONTROL
MAX. SPEED ADJ.
IDLE ADJUSTMENT
PRIMARY MANIFOLD
SECONDARY MANIFOLD
FUEL PUMP
EXH. NOZZLE ACTUATOR CONTROL
AFTERBURNER FUEL CONTROL
AFTBURN IGNITER
LOW PRESSURE COMPRESSOR
HIGH PRESSURE COMPRESSOR
BURNER
TURBINE
BURNER
MAIN ACCESSORY SECTION
STARTER

Figure 11-20. Jet Engine Diagrammatic Work Sheet for use in conjunction with Jet Engine Training Device shown in Figure 11-19.

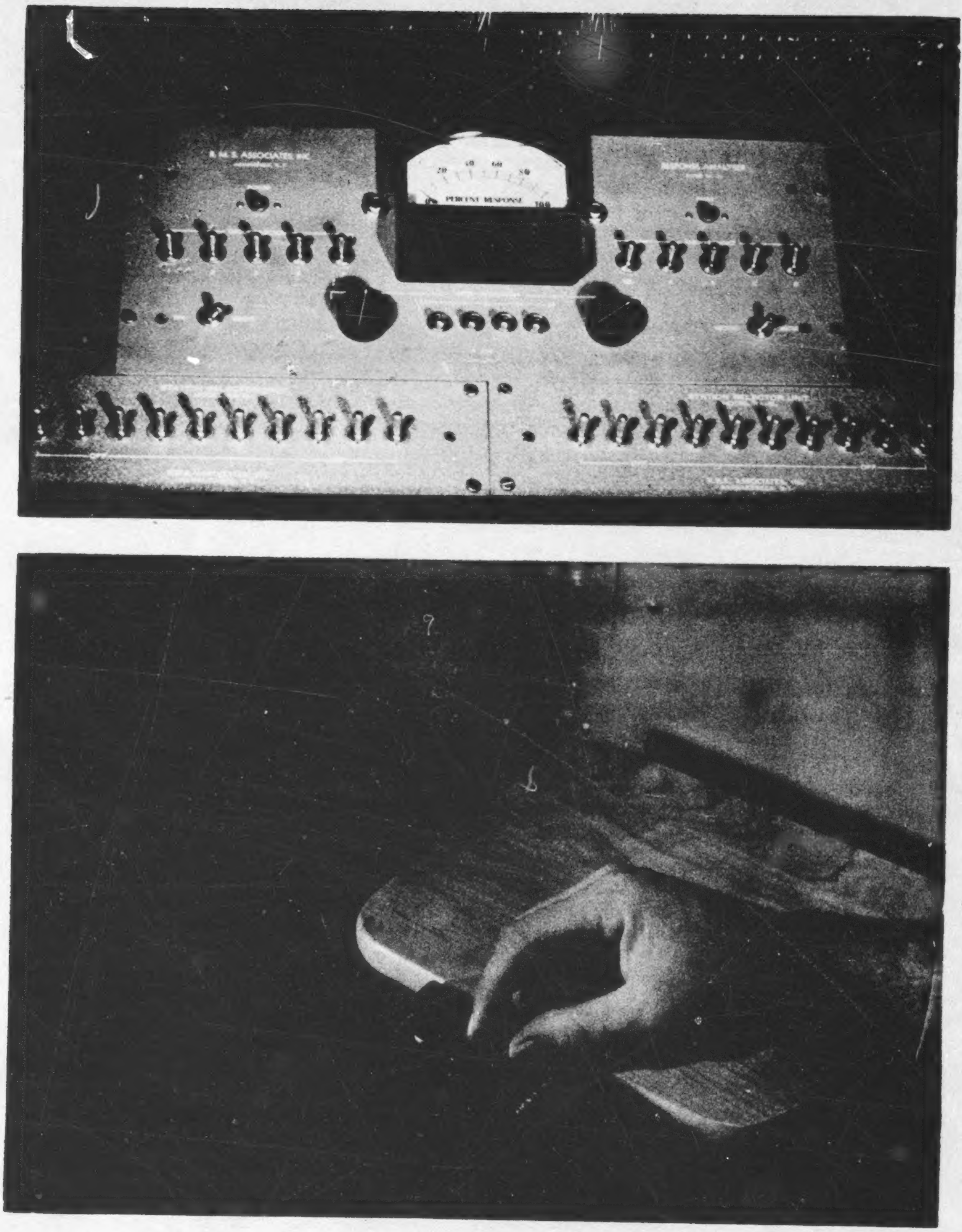
R. M. S. ASSOCIATES, INC
20 40 60 80
PERCENT RESPONSE
100
RESPONSE ANALYZER
SYSTEM SELECTOR UNIT

Figure 11-21. Class-response Equipment to Allow Active, Scored Responses to Questions in a Class Situation. Students use selector switches, shown in lower picture, to register their answer choice. Proportion giving each response is displayed to instructor by the meter on the panel shown in the upper photograph. Accessory equipment can be used to furnish a permanent record of each student's performance.

With but little more instrumentation, the classroom-response equipment can also be made to indicate the responses of individual students to the instructor, so that he is enabled to direct further questions at any individual student.

Preliminary Tryout of Prototype Training Devices

Often a tryout of a very preliminary form of prototype of a training device may pay large dividends in improving subsequent devices. A special use of the student-response devices just discussed is in testing a preliminary version of an instructional presentation, such as a motion picture film, which is later to be standardized. Doing this will often result in clarification of many errors, misconceptions, or failures of comprehension which would otherwise go unnoticed but which, once detected by such a technique, can be readily rectified by modifications in the presentation.

The construction of a preliminary version of a training device (even in such a crude form as that shown in Figure 11-7, for example), and its tryout with sample groups of typical students, will often result in great improvement of the final product. This kind of tryout with a preliminary "breadboard" mock-up is, of course, standard procedure for detecting deficiencies and improving design to obtain better equipment functioning. Unquestionably, it would be very beneficial to extend this rationale to the development of almost all training devices also, in order similarly to improve the "output" of such devices as measured in terms of the amount of learning resulting from the use of the device. The most straightforward application of this is afforded in instances where the instructional device will be a "self-contained" one as in the case of a film or teaching machine.

In the case of an instructional film, an extremely crude presentation either in the form of a film strip, a preliminary "take" of the motion picture sequences, or even a "live" presentation to students of what is going to be later filmed, can contribute a great deal in this respect. Research evidence indicates that very often the instructional characteristics of such a crude preliminary version are closely similar to those of a final, polished product if the latter, despite its "polish" and technical refinements, retains substantially the same sequence of basic verbal instruction and visualization ideas (see May and Lumsdaine, 1958).

For example, in the illustrative data shown in Figure 11-22, the relative amount learned on different test items corresponded very closely between the test scores of a group that was shown a preliminary film strip and a group that was shown a final polished film following the same sequence of presentation (Zuckerman, 1954). This was true despite the fact that the visual materials used in the preliminary film strip were extremely crude as compared with the slicked-up presentation afforded in the final film. (A recent, unpublished study by Gropper and Lumsdaine has also demonstrated the feasibility of effecting significant improvements in the effectiveness of a film (or TV lesson) by using inputs from tryout test data for a preliminary

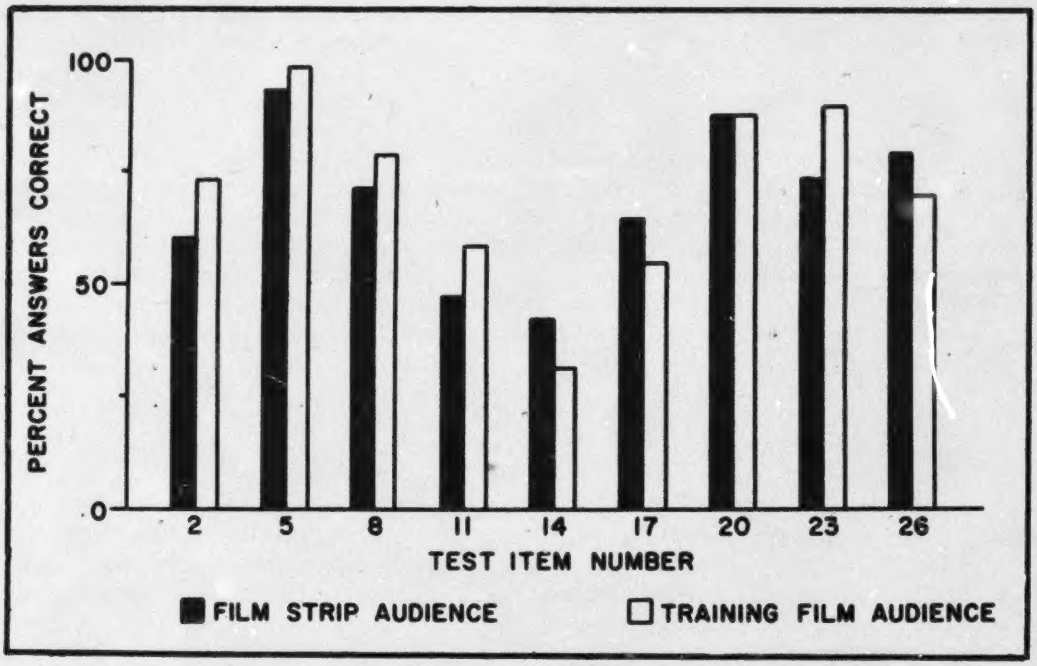

Figure 11-22. Comparative Item-by-Item Teaching of Preliminary and Final Forms of a Training Film.

presentation as a basis for improving the final film.) The moral in the comparative data for crude and polished presentations unquestionably applies to many other forms of training devices. The payoff is in the sequence of ideas, associations, appropriate response opportunities, and other factors that psychologists have found will contribute to effective learning--and not, primarily, in the slickness of the device in terms of fancy photography, artistic rendering, or chrome trimming. The latter may possibly have some effect on acceptability to students and their consequent motivation (though this has never been clearly demonstrated). More likely, their major effects may simply be in impressing training supervisors and administrators, and may have relatively little to do with the effectiveness of a device for training. In some instances "fancying up" a training presentation may even have an adverse effect on learning, as was found in a study reported by May and Lumsdaine (1958) for the case of the injudicious use of cartoon illustrations and other humorous effects in a training film designed to teach verbal identifications.

Simplification and Realism in Displays

One important factor in the design of displays designed for multiple training functions in classroom teaching is the kind of depiction employed to represent components and interconnections. For purposes of learning to identify individual components or parts, realistic depiction through display of a realistic drawing or photograph (or, if more convenient, the actual component) is obviously advantageous. However, highly simplified representation of components has been demonstrated by Swanson, Lumsdaine and Aukes (1956) to be superior in explaining functional interconnections of a system. Apparently, the simplified representation of components permits focus of attention on the functional interconnections by eliminating the distractions present when the components are realistically depicted. This differential advantage for different forms of depiction for meeting the various objectives of training is a further argument for using simple, flexible aids which can be introduced or changed as required at each point in instruction.

Motivational Factors in Training Device Design

In the foregoing discussion, motivational factors entering into training device design have been mentioned as they were appropriate, particularly in relation to certain classes of device. The control of student motivation is sometimes a difficult problem, and assuring an adequate level of motivation is unquestionably essential in any training program. Major factors that affect this motivation, however, often lie largely in the realm of situational factors, including leadership and provision of a satisfactory student environment and living conditions. These may be factors which can greatly outweigh those which can be directly influenced by the designer of training equipment. A few general comments, however, are appropriate here.

The design of training devices is sometimes unduly influenced by a desire to make them "interesting" and attractive to students. Sometimes this can be usefully done in a way that does not compromise the other features of the device. Frequently, however, if other environmental conditions are satisfactory and reasonable standards of student selection have been exercised, the importance of special "motivational" gimmicks and display features designed presumably to enhance motivation may be easily exaggerated. As has been noted, indeed, sometimes when an attempt to provide these takes the form of "fancying up" the device in an injudicious manner, distractions may result which may interfere with the attention of the student to the essential task to be learned, and thus have an adverse effect on learning rather than a beneficial one.

Perhaps the most adverse effects on motivation that can be created by a device occur, however, when the student is frustrated by having too much material presented to him for him to master effectively, or by being required to learn things that he does not perceive as essential or important for the job for which he is being prepared. One of the outstanding advantages of self-instructional devices that regulate the rate of progress to each student's ability and provide for frequent checking and correction in an impersonal, automatic manner is that they tend to avoid such frustrations and hence keep up the student's interests, satisfactions and general level of accomplishment.

Persuading the student that arduous sessions of training are necessary in order for him to master things that he really needs to know for successful job performance may also sometimes be very important. Effective motivation may sometimes depend largely on his being initially convinced that the instructor and designers of the training devices "know their stuff." The student may need to be shown at the outset how in a general way the skills and knowledge that he is being required to attain will be needed for successful job performance. Often this can be best accomplished by good instructor leadership, although sometimes special "indoctrination" or "orientation" devices, particularly well-designed films, may contribute to this end.

In general, such films should not try to confound this persuasive or motivational purpose with a specific procedural training objective. Their successful design may depend less on cinematographic and artistic virtuosity than on a sound appraisal, based on objective evidence if possible, of the attitudes, interests, misconceptions, etc., of the student, which may need to be corrected for him to perceive the importance and worthwhileness of what he is being asked to learn. In addition, their effectiveness is likely to be primarily determined by skill in presenting information that fosters the desired attitudinal and motivational objectives. The design of such persuasive messages is generally not within the province of the designer of training equipment. However, interested readers may find some pertinent guidelines in recent work on factors affecting persuasion and attitude change, particularly in publications by Hovland, Janis and Kelly (1953) and Hovland (1957).

Summary

1. The disadvantages of classroom lecture-demonstration as a method of instruction can be partly offset, where it is to be used, by making provision for a maximum of active student responding. This can insure rehearsal of important aspects of the subject and can detect and correct errors promptly. Careful design of instructional exercises, provision for suitable modes of student response, and prompt feedback to students are essential to the success of such procedures. Using devices which also provide an immediate record of student response to the instructor can help him in clarifying his presentation.

2. Tryout of all forms of training devices in preliminary or prototype form to determine empirically how well they teach a sample of students can result in greatly improving the effectiveness of the final device. Often, relatively crude preliminary forms suffice quite well for this purpose.

3. Slick "polish" and fancying up of training devices is likely to contribute little or nothing to their training effectiveness, and may even have adverse effects. Student motivation is less affected by such frills than by a satisfactory training environment, competent instructors, adequate orientation, and sound procedures that permit the student to progress toward mastery of his subject and to keep up his awareness of accomplishment.

4. Specific motivational procedures need to be based on sound appraisal of the interests and misconceptions of students, and should take into account available guidelines on effective techniques of persuasion and attitude formation.

Procedures in the Design of Training Devices

Major Steps Required

A logical outline for the design of training devices for a given job might comprise the following major steps:

1. Determine in detail the human performance requirements for the job.
2. Formulate training requirements in terms of the new knowledges and specific skills that will need to be acquired, taking into account the characteristics of the persons to be trained.
3. Plan a total program of training through which trainees can master these skills and knowledges to the level of proficiency required for successful job performance.
4. Determine the logistic requirements for a combination of instructors, facilities, training devices and training materials that will accomplish this program.
5. Devise mock-up or tentative prototype devices, and provisional training procedures. Give these a full try-out, using trainees as similar as possible to those for whom the final training is intended, and assess the outcomes in terms of proficiency attained and time required for training.
6. Revise the devices and procedures to correct deficiencies. Try-out the revised procedures as necessary to demonstrate that they will do the job, as determined by valid and reliable measures of performance (see Chapter 13). At this point, re-engineer the devices for reliability of operation, ease of maintenance, and (if required) quantity production.

Note that the design of training devices themselves forms only a part of this outline, and enters only in the three last steps. The reason for this is that otherwise there is no way to assure that the devices will fit into a total program of developing the personnel capabilities required for the performance of a job. The major steps identified above obviously do not define detailed procedures for the design of training devices; they merely provide the framework within which such procedures can be developed. Situations for which training devices need to be designed differ so widely that no rigid prescription is possible that will fit all cases. However, most of the procedures and guidelines suggested here can be adapted or modified to meet specific cases, drawing on concepts and specific device characteristics that have been illustrated throughout this chapter.

The guidelines given below are based on the situation where the designer is given responsibility for the design of all the training devices and supporting materials needed to train a man to fill a particular position in a complex system that is under development. Here there is usually a fairly definite production timetable that specifies when the training devices will need to be ready in quantity for training a given number of men to fill this position. This calls for careful scheduling and procurement planning, in addition to the basic design problems of determining what training-device configurations will do the needed job of training.

Successive approximation. Detailed steps of procedure, and even the gross steps outlined here, usually can not be followed completely in a prescribed order. This is because early estimates of one aspect of the total plan--job performance requirements or selection standards, for example--usually are subject to change. Changes in one aspect will inevitably require changes in others. Since the preliminary estimate of needed training-device characteristics ordinarily cannot await the final redetermination of performance or manning requirements, what is usually needed is a series of successive approximations. While these are being carried out, provisional design and procurement actions for training devices should be initiated as early as necessary to insure that the means for providing trained men will be ready when needed, even though considerable redesign may be necessary as requirements change. This process of successive approximation will be assumed in what follows.

System Inputs to Training-Device Design

Determining of performance and training requirements should normally be accomplished prior to the design of training procedures and devices. Sometimes, however, all the necessary information is not made available. In this case, as a training-device designer you should yourself try to estimate performance requirements as well as possible, checking these estimates in consultation with available sources of information. In doing this, try to anticipate not only what human outputs will be required, but also: (1) the way job knowledge requirements will be affected by the availability of job aids; (2) the baseline from which training will start, in terms of prior capabilities on which training can be built; and (3) the specific prerequisite competences which will be achieved through phases of training other than that for which you are responsible.

Analysis of Training-Device Requirements

Classify the skills and knowledges required into the major types of training objectives outlined in this chapter: (1) identifications to be learned, (2) principles to be learned (those actually needing to be used in job operations), (3) procedural sequences to be followed, (4) diagnostic problems to be solved and other decisions the trainee must learn to make, and (5) motor skills needing to be acquired and practiced. (For some jobs, there may be no entries under one or more of these classes.) List under each category the specific instances, first in broad groupings. Later break this down into finer detail. The final list should be such that it completely defines the set of performances which a proficiency test should assess to reveal whether a man can actually do the job.

In working out device requirements for these categories of training objectives, it may be well to start with the last one (motor skills) and work backward. The reason for this suggestion stems from the likelihood that the latter categories will require operational equipment components that have a long production lead-time.

Preliminary Design Estimates Having Logistic Implications

For each major set of items under each class of objectives:

1. Determine those which must be taught on operational equipment or a simulator (e.g., complex motor skills), and those which--considering the number of men to be trained--can most economically be taught through practice on operational equipment.

2. Determine those which--particularly in the class of identification training and preliminary training of fixed procedures--can be taught by use of photographs, drawings, simple replicas or partial components.

3. Determine those--particularly for learning of principles--for which verbal and symbolic materials to give extensive symbolic practice are needed.

4. Determine those which require synthetic devices to provide sufficient practice in a variety of relatively seldom encountered situations--e.g., troubleshooting or emergency procedures. Design these tentatively, and on this basis estimate the number of production-line equipment components, large or small (from knobs to amplifiers and servo systems) that must be allowed for in production schedules.

5. For training that requires production-equipment units or components, indicated in items 1, 2, and 4 above, specify the training procedures to be followed, estimate (on the basis of past experience in teaching similar procedures) the amount of time needed to learn them to an acceptable criterion of mastery, determine the number of men to be trained, and thus determine the total number of units and components needed. Then order these as early as necessary to assure they will be available (but not sooner, as your estimates will be subject to later revision).

6. Do similarly for non production-line items required in 2, 3, and 4 when needed as a basis for procurement.

Further Steps in Device Design and Development

Now proceed to work out in detail the materials, devices and procedures needed for training, construct mock-up materials, try these out in actual instruction, and revise the designs for production. Coordinate your planning as fully as possible with the work of others engaged in the planning and design of handbooks, other job aids, and performance assessment devices. This will assure compatibility of terminology, and of representations and coding in diagrams and other visual aids, as between handbooks, training device displays, and other training materials.

Working assumptions in developing detailed designs. As a basic operating principle, work on the initial assumption that all training is going to be accomplished through individual student practice on an appropriate program of exercises. Later it may be necessary to depart from this working assumption, for various reasons, and resort to classroom-presentation methods. But starting with this assumption will have two advantages: (1) if carried through, it will result in superior training, and (2) even if not, it will force you to pay attention to the conditions necessary for an individual student to practice and learn each thing he must master, thus avoiding the fallacy that what is presented will necessarily be learned.

Some Procedural Guidelines for Troubleshooting Training Devices

1. Start by simplifying the requirements for troubleshooting training as much as possible by devising proceduralized troubleshooting guides or similar job-information aids which can be made available for use on the job. Determine the extent to which these can be used to locate most of the common, easily-identified malfunctions without need for extensive education on system principles, especially if location of the more elusive malfunctions is turned over to a small number of highly trained technicians by a job shred-out procedure.

2. For the techniques and strategies of malfunction diagnosis that men must learn to devise on the job, assure sufficient practice in the interpretation of malfunction symptoms, and practice in making the decisions needed to choose effective courses of action.

3. Determine whether to provide this practice through one or both of two types of training device: (a) "hardware" trainers using simulated plug-in units, and simplified indicators and controls (see p. 246), in which the effects of a wide range of malfunction conditions can be readily inserted for the student to diagnose; and (b) programmed exercises in symbolic form (see pp. 252 and 321). Design or select suitable devices in these categories.

4. Consider the design of composite devices (see p. 253), in which readily reprogrammed problem-and-information presenting devices are coupled with simple mock-ups of the external configuration for a particular system by use of coded inputs.

Guidelines for Designing Procedural Trainers

1. Try to reduce the sheer memory requirements for recalling lengthy procedural sequences by assuring the availability of suitable job aids, and design training to prepare men to use these aids effectively.

2. For effective teaching of all sequential procedures required on the job, break-down lengthy tasks into shorter ones and design explicit, pictorialized step-by-step instructions that can be readily followed if basic identifications and unit skills have been taught.

3. If possible, translate these into step-by-step filmed demonstrations that are designed to allow immediate practice after each step of the demonstration, preferably on an individual basis or, if necessary, on a class basis.

4. In providing implements for guided practice of procedures, utilize, wherever possible, incomplete components, surface mock-ups, or inexpensive replicas, reserving the use of functioning equipment primarily for those procedures which impose the need to respond to complex displays or to learn the "feel" of the response. Obtain the units, components or replicas in quantities that will allow for sufficient intensive practice to assure "overlearning" of crucial operations.

5. For complex procedures, determine whether it is more economical to provide adequate practice and feedback through a combination of simulated and real components, using special circuitry, or to use operational equipment. In designing such equipment, determine where substituting of simple "go/no-go" indicators to indicate equipment conditions will reduce cost without materially changing the critical elements of practice.

Design Steps for Devices to Teach Principles and Relationships

1. As the first and most basic step, identify those principles which will actually need to be applied in performing job activities. Spell these out in detail. Ignore principles that underlie the physical functioning of the equipment unless these will help to make decisions or to recall procedures needed on the job.

2. Design training equipment and materials to tie in with procedures that will afford practice in recognizing the application of the principles identified, and in actively employing them as a guide to job operations. In doing so, first develop a program of exercises to provide this extensive verbal or symbolic manipulation, then develop the displays and devices for controlled presentation and checking of the exercises to individual trainees, utilizing self-instructional devices (see Chapter 12) if possible.

3. If you are dealing with a highly complex system, try to make an exhaustive prior analysis and systematic tabulation of the multiple interrelations among malfunction conditions, mode of operation and output indications. Use this as a basis for designing training exercises and devices for troubleshooting, as well as for identifying relevant principles that may be applied in troubleshooting or other operational decisions which the trainee will be called on to make.

Guidelines for Teaching of Identifications

1. For effective learning of the numerous identifications likely to be required in performing each task, insure controlled, active practice by students, rather than mere presentation. Either use self-instructional devices with suitable programs of material or provide materials suitable for use by the coach-and-pupil methods, using simple aids such as photographs, drawings, and printed labels and lists.

2. Design practice materials and schedules so that they take account of the direction of association required in job activities (see p. 230).

3. Include in these programs the basis for teaching knowledge of all required "facts" by similar practice on the basic one-to-one identifications to which they may be reduced.

4. Though you may have left the preparation of identification training devices until last for logistic reasons, do not minimize the importance of this phase of training, on which the success of later phases of training will often heavily depend.

Empirical Try-out of Training Devices

A most important step which should never be omitted is the tryout of all forms of training devices in preliminary or prototype form to determine empirically how well they teach a sample of students. Time to accomplish this should always be allowed, as it can result in greatly improving the effectiveness of the final training devices. Often it will suffice to use relatively crude preliminary forms of the devices for this purpose--employing, if necessary, supplementary instructors who may later be replaced by partial automation of functions they perform during the try-out (see pp. 280 and 325).

In selecting the men to be trained in the try-out, err if anything on the side of including some men with somewhat less aptitude and experience than those you expect will later have to be trained operationally. However, after the try-out, determine whether the extent to which the training requirements could be reduced if higher selection standards were used, or if there were better job aids or job structuring. You may then wish to determine whether it is feasible to change selection requirements or job conditions to reduce training needs, rather than adding to the resources needed for a training effort which could be simplified by one of these means.